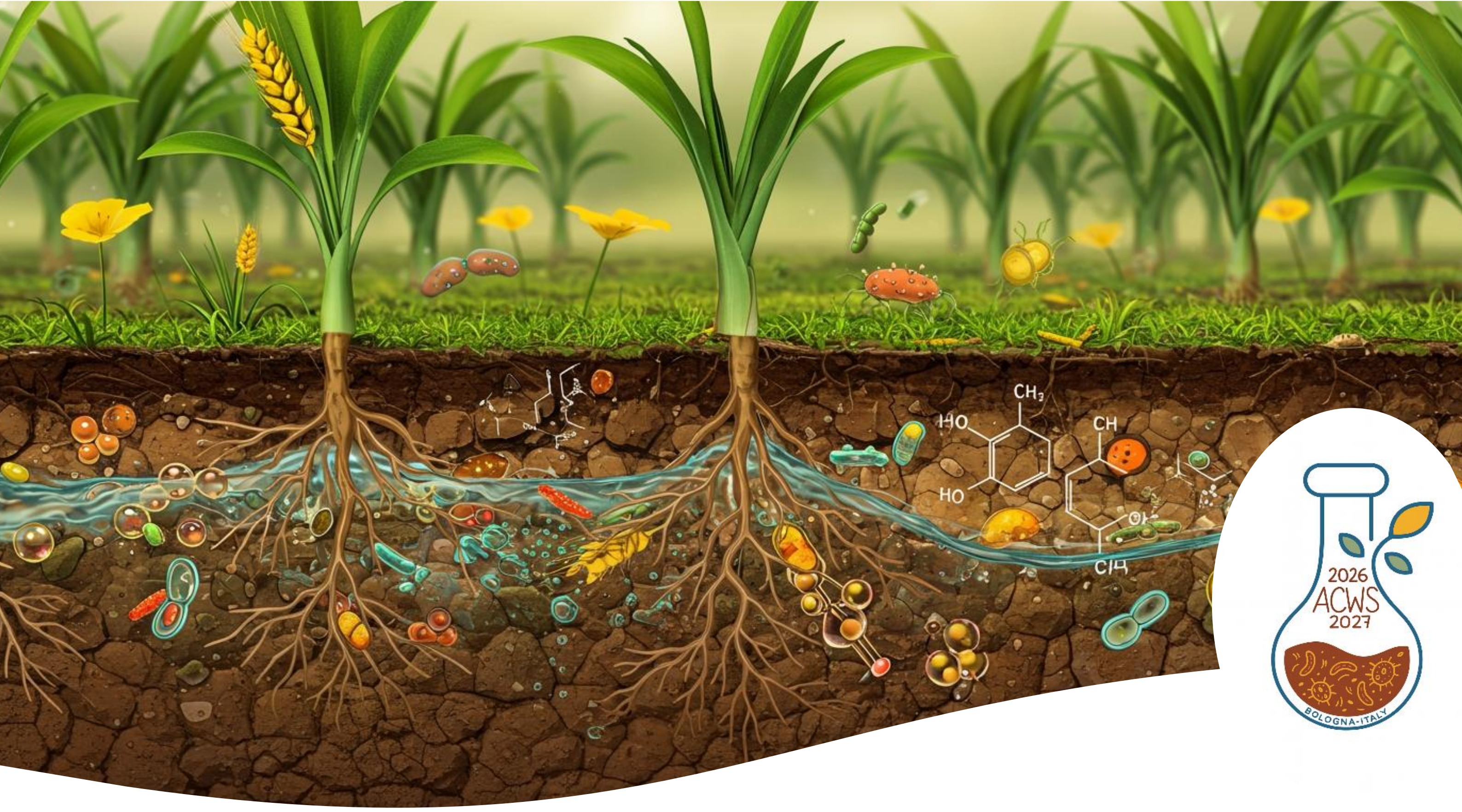

AGRICULTURAL CHEMISTRY WINTER SCHOOL

SOIL-PLANT-MICROBIOME FUNCTIONALITY AND ADAPTATION TO ANTHROPOGENIC STRESS AND CLIMATE CHANGE

BOOK OF ABSTRACT

SICA

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RECOVERY AND NUTRIENT USE EFFICIENCY OF PHOSPHORUS FROM UNCONVENTIONAL SOURCES

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Keywords: phosphorus recovery, sustainable waste management, circular economy

Phosphorus (P) is vital for global food production, but phosphate rock reserves are finite and face growing geopolitical and environmental constraints. P-rich organic wastes (sewage sludge, animal manure) remain underutilized due to pathogens and heavy metal (HM) contamination. Safe, circular, cost-effective P recovery technologies are urgently needed. This project optimizes incineration-derived ash as a sustainable fertilizer resource.

Incineration destroys pathogens, reduces volume, and stabilizes contaminants unsuitable for recycling [1]. Optimizing peak temperature, residence time, oxygen supply, feed preconditioning, and the selection and addition of suitable additives influences ash mineralogy, enhancing P extractability while reducing HM mobility [2].

Stage 1: Test optimized incineration combined with additives (e.g., $CaCl_2$, eggshell, oyster shell [3]) to enhance HM removal and convert P to soluble forms.

Stage 2: Use selective low-concentration acid leaching on optimized ash to maximize P dissolution while minimizing HM co-extraction, producing high-purity P.

Ash will be analysed by XRD and ICP-OES for P speciation, mineralogy, nutrient content, and HM levels relative to fertilizer standards. Agronomic tests via pot trials with model crops will assess biomass, P uptake, and chlorophyll content compared to commercial fertilizers. Field trials will evaluate long-term soil P availability and HM behaviour.

The project aims to deliver a cost-efficient process for high-purity, plant-available P fertilizers from incinerator ash. Expected outcomes: optimized conditions reducing HM content and fertilizer performance comparable to commercial alternatives. It supports EU Circular Economy goals and UN SDGs "Zero Hunger" and "Life on Land".

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INVESTIGATING THE IMPACT OF WARMING ON SOIL ORGANIC CARBON POOLS AND CROP YIELDS

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Keywords: climate change, carbon sequestration, sugar beet, soybean

Soil organic carbon (SOC) represents a major component of terrestrial carbon storage and plays a critical role in soil functioning and the global carbon cycle, regulating climate-carbon feedback. Quantifying the response of SOC pools to rising temperatures is essential for predicting soil-atmosphere carbon fluxes and sustaining agricultural productivity under future climate scenarios. This study investigated the effects of experimental warming (~ +2 °C) on SOC dynamics and crop yields within a soybean-sugar beet rotation system in northern Italy over two years (2023-2024). A randomized complete block design with open-top chambers (OTCs) was applied, and topsoil samples (0-20 cm) were physically fractionated into mineral-associated organic matter (MAOM) and particulate organic matter (POM). Carbon stocks and distribution, thermal and biological stability, were assessed using CHNS analysis, TGA-DSC, and incubation experiments. The induced warming generated crop-specific responses: SOC stocks decreased in soils cultivated with sugar beet (range: 1.4-5%) while they increased in those cultivated with soybeans (range: 3-6%), reflecting differences in root structure and residue inputs. MAOM/POM ratio decreased with warming in 2023 in all soils, while it increased in sugar beet soils in 2024, probably because of the rotation with soybeans. Thermal analysis revealed that warming and crop type significantly affected the thermal stability of SOC fractions. MAOM showed higher energy density than POM, confirming its greater stability. Crop specific responses were evident particularly in soybean, with reduced MAOM stability under warming, while sugar beet showed the highest MAOM thermal stability in both years. POM was more responsive to temperature increase, particularly in 2024, indicating enhanced vulnerability of labile SOC pools under warming. The cumulative CO_2 values obtained from incubation tests (basal respiration) showed greater SOC lability in soybean soils. Yields have fallen dramatically as a result of warming (-70% for sugar beet and -80% for soybean) with estimated economic losses of approximately 3,000 and 1,000 €/ha, respectively. This highlights the need for integrated, evidence-based policies to steer the Common Agricultural Policy towards agricultural practices that protect SOC and ensure production security in the context of climate change.

THE ROLE OF SOIL COMPACTION IN MODULATING RHIZOSPHERE DEVELOPMENT IN HAZELNUT ORCHARDS

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Keywords: *Corylus Avellana* L., roots, zymography, soil enzymes, porosity

In rural areas of North-Western Italy, hazelnut orchards (*Corylus avellana* L.) represent one of the main and most profitable permanent crops, with 27,685 ha cultivated in Piedmont [2]. Soils underneath these crops are characterised by paucity of soil organic matter (SOM) and are typically compacted, with bulk density values as high as 1.7 kg/dm^3. The movement of agricultural machinery strongly alters soil structure: it causes compaction, reduces total porosity and the natural soil pore connectivity, and affects the shape of the aggregates, with direct consequences on air and water circulation, and on the root exploratory capacity [1]. In low fertility soils limitations in root development may deeply alter nutrient uptake and crop yield.
We hypothesize that a higher degree of compaction hamper root formation but may be counterbalanced by an increase in soil fertility (addition of organic fertilizers), that may enhance root and rhizosphere extension, or by an increase of enzymatic activity.
Soil bulk density, aggregate composition and resistance, and soil porosity will be analysed in both bulk soil and rhizospheric soil under varying conditions. Soil zymography [3] will be used to investigate the enzymatic activity along roots in field and pot experiments.
The present study will possibly reveal that while a reduced volume of soil is explored due to the presence of a physical barrier, the plant will implement strategies to cope with the stress. Also, the addition of different types of fertilizers will clarify which compounds have more beneficial effects.
The results could be extended beyond Piedmont to other hazelnut orchards in Italy and foreign countries, and in general to compacted soils under permanent crops around the world.

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ISOLATION AND GROWTH CHARACTERIZATION OF BACTERIAL SPECIES CAPABLE TO DEGRADATE PESTICIDES

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Keywords: Bioremediation, Pesticides degradation, microorganisms

Current agricultural production systems rely extensively on chemical agents to protect crops and promote plant growth. However, these compounds are known to exert negative effects on ecosystems. In particular, pesticides pose a significant threat not only to target organisms but also to non-target species, including pollinators, thereby compromising key ecosystem services. Here, we present initial advances toward the development of biological tools for the degradation of commonly used pesticides through bacterial activity. Bacterial strains were isolated and screened for their ability to grow in the presence of pesticides as the sole carbon source using minimal growth media. Growth was evaluated in the presence of acetamiprid, glyphosate, and a mixture of tebuconazole and fluopyram. For selected isolates, growth kinetics were characterized using a TECAN Spark microplate reader. Bacterial cultures were incubated for one week at 27 °C under continuous agitation, and optical density was recorded hourly to monitor growth dynamics and adaptation to pesticide-containing environments. The results presented here derive from the combined efforts of a doctoral research project and a postdoctoral fellowship. Ongoing and future work aims to integrate these findings into the development of a microbial-based formulation for bioremediation. This strategy is intended to address not only soil contamination but also pesticide exposure in pollinator colonies, both managed and wild, thereby contributing to the preservation of pollination services and ecosystem sustainability.

GREEN STRATEGIES TO EXTRACT PLANT-DERIVED BIOACTIVE MOLECULES FOR WEED CONTROL

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Keywords: Biopesticides, Phytotoxic compounds, MAE (microwave-assisted extraction), Photodegradation, Circular economy.

The transition toward a circular economy requires innovative strategies to reduce agricultural waste while simultaneously minimizing reliance on synthetic agrochemicals. Conventional herbicides, although effective in weed management, are increasingly associated with environmental contamination, biodiversity loss, soil and water degradation, and potential risks to human health. In this context, plant-derived bioactive molecules represent a promising avenue, as many species naturally produce secondary metabolites with intrinsic phytotoxic or allelopathic properties. Harnessing these compounds not only supports more sustainable agricultural practices but also contributes to the valorization of biomass currently treated as waste. This study aims to investigate the potential of phytotoxic molecules present in discarded tissues, specifically leaves and branches, from eight different plant species. These materials were chosen based on preliminary evidence suggesting the presence of phytotoxic secondary metabolites as well as their widespread and easy accessibility within agricultural, domestic, and urban environments. The approach aligns closely with circular-economy principles aimed at reducing waste streams and maximizing resource efficiency. The collected plant residues were processed to obtain crude extracts through microwave-assisted extraction (MAE). This environmentally friendly technique reduces processing time and energy consumption compared with conventional extraction methods. A mixture of ethanol and water (50:50, v/v) was used as the extraction solvent, providing a greener alternative to purely organic solvents. The solvent was subsequently recovered using a rotary evaporator, enabling its reuse and further minimizing the environmental footprint of the process. Extraction yield and total phenolic content (TPC) were quantified for each plant species to assess differences in their chemical profiles.
TPC analysis demonstrated that walnut exhibited the highest phenolic content, highlighting its potential as a particularly rich source of bioactive compounds. Bioassays confirmed that several extracts displayed measurable inhibitory effects on seed germination, supporting their potential application as natural herbicidal agents.
Overall, these findings indicate that phytotoxic molecules obtained from vegetal waste could serve as promising candidates for the development of next generation bioherbicides.

ENHANCING SOIL RESILIENCE THROUGH SOIL NATURE-BASED SOLUTIONS: INTEGRATING ENVIRONMENTAL, SOCIAL, AND ECONOMIC DIMENSIONS OF SUSTAINABLE SOIL MANAGEMENT FOR CLIMATE RESILIENCE

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Keywords: Nature-based solutions, soil health, agricultural management, soil amendments, desertification

Soil degradation affects around 75% of global soils, threatening food security, ecosystem services, and climate resilience. This ongoing PhD research addresses these challenges by evaluating the role of soil nature-based solutions (NbS) and soil management practices in enhancing soil quality, mitigating degradation, and promoting sustainable resource use under current and future climate pressures. The study proposes a methodological framework linking NbS implementation, soil management, and environmental sustainability through indicators such as carbon footprint, water footprint, and microbial activity. It also examines soil nutrient dynamics (N, P, K), erosion control, and organic matter loss, while assessing the role of biodiversity and vegetation cover in improving soil structure and fertility. Beyond environmental aspects, the research incorporates social, economic, and governance dimensions, focusing on citizen participation, policy coherence, and financial mechanisms that support the large-scale adoption of sustainable practices. The thesis combines systematic literature review (first stage), field and lab experimentation, and integrated sustainability assessment. In the first stage, a broad review of soil NbS literature identified persistent barriers such as limited long-term adoption, insufficient funding options, and low social acceptance, often linked to the lack of inclusive governance and stakeholder engagement. The second phase (ongoing) involves comparative trials using different agricultural practices or soil NbS (digestate and manure application) to evaluate microbial responses, nutrient retention, and potential pollution risks, providing data for scenario modelling and upscaling. The final phase will merge environmental, economic, and social indicators through Life Cycle Assessment (LCA), Life Cycle Costing, and Social LCA, generating an evidence-based tool for assessing sustainability performance and informing agricultural and forest policies. Expected outcomes include demonstrating the improvement of soil quality, the reduction of erosive and contaminating processes, and quantifying the benefits of circular resource management and green innovation. Ultimately, this thesis aims to deliver a scientifically grounded and socially inclusive framework for resilient soil management, supporting climate adaptation, ecosystem restoration, and long-term sustainability in Mediterranean and other climate-vulnerable regions worldwide.

CLIMATE-DRIVEN SHIFTS IN OLIVE SUITABILITY ACROSS THE MEDITERRANEAN BASIN

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Keywords: future climate scenario; crop suitability; MaxEnt; species distribution models; aridity index

Climate change is reshaping Mediterranean agroecosystems, posing a challenge to the resilience of traditional perennial crops. Olive (*Olea europaea* L.), a keystone species of Mediterranean landscapes, is facing increasing challenges for its cultivation in traditional areas. This study quantifies current climatic drivers of olive spatial distribution and projects future suitability across the Mediterranean Basin using a MaxEnt species distribution model calibrated with 7,490 occurrence records and eight bioclimatic predictors. Suitability was assessed under two contrasting CMIP6 scenarios (SSP1-2.6 and SSP5-8.5) for mid-century (2041-2070) and late-century (2071-2100) periods.

Minimum temperature of the coldest month emerged as the dominant driver (>50% contribution), highlighting cold stress as the primary physiological constraint shaping the northern distribution limit of this crop. Precipitation of the wettest month was the second most influential variable, reflecting the species' dependence on adequate water availability despite its well-known drought tolerance. Model projections indicate a pronounced northward shift of suitable areas, particularly toward France and the Balkan Peninsula, while traditional southern regions remain generally suitable but increasingly exposed to heat extremes, reduced winter chilling, and intensifying aridity. Post-hoc evaluations of soil types and aridity index suggest that these factors modulate local vulnerability but have limited predictive power at the basin scale with the actual data resolution.

Overall, our results reveal a spatial reorganisation of future olive orchard landscapes driven by interacting temperature and water stresses. They underscore the need for anticipatory adaptation strategies, such as selecting stress-tolerant or cold-resistant cultivars, implementing deficit-irrigation management, and leveraging topographic refugia to sustain olive production in a warming and increasingly variable climate. This study provides a basin-wide, spatially explicit framework that supports climate-resilient planning for perennial crops facing rapid environmental change.

INFLUENCE OF DIGESTATE APPLICATION IN MOUNTAIN GRASSLAND AS A POSSIBLE STRATEGY TO INCREASE THEIR RESILIENCE TO CLIMATE CHANGE

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Keywords: digestate, mountain grassland soil, climate change, soil organic carbon, soil nutrient

The mountain environment is an ecosystem sentinel for global climate change, which will negatively affect soil properties and determine phenology shifts. Grasslands cover about 70% of agricultural land and they can store about 34% of the global carbon stock, depending on climatic conditions and land management. The current grassland ecological degradation affects their ecosystem services.
The digestate, which contains organic matter and plant-available nutrients, can have amendment properties and can allow for the replacement of inorganic fertilizers. Now, it's being increasingly used in mountain areas. The dynamics of soil organic matter (SOM) in mountain meadows are unclear, and the antagonistic and synergistic interaction between climate change and management practices (including amendment) have yet to be understood.
The present research project aims at examining the effect of digestate application on SOM biogeochemical characteristics, distinguishing POM (particulate SOM) and MAOM (mineral associate SOM) in topsoil from grasslands, also considering a possible climate change scenario simulated using open top chambers. To achieve this goal, two experimental fields (randomized blocks) will be set up and monitored for 2-3 years, and 6 theses tested, i.e., increasing temperatures (ambient *vs.* + 2°C), amendment (unamended vs. digestate application), and application times (2 *vs.* 4). In fact, as the timing of amendment can have an influence on C:N:P stoichiometry, the same quantity of digestate will be distributed differently, i.e., in spring and autumn rather than around the time of meadows cutting. Physical, chemical and biological properties will be investigated, including SOM evolution/stability (by soil respiration and thermal analysis), as well as fodder production and nutritional quality.
The obtained results will contribute to improving the knowledge about the interaction between agronomic practices (fertilization, cutting), SOM dynamics and associated ecosystem services (e.g., carbon storage, fodder production, climate change mitigation and biodiversity preservation) in mountain grassland soils. Moreover, they may be useful to increase the awareness of farmers on the role of healthy soil in sustainable livestock in mountain areas.

ADVANCED MONITORING OF VINEYARD SOILS TO SUPPORT SUSTAINABLE AGROECOSYSTEMS

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Keywords: Vineyards, Biological, Conventional, Soil quality, Soil fertility

Intensive grape production has dramatically impacted chemical, physical, and biological soil fertility due to the significant inputs of agrochemicals and fertilizers. This work aims to identify the biotic and abiotic drivers of soil quality and the keystone species influencing it, applying an innovative agroecological network analysis in vineyards based on their management and geographic location. The sampling area is in South Tyrol (Italy), one of the highest-quality viticultural regions in Italy. One thousand eight soil samples associated with Vitis vinifera cv. Pinot Noir were collected from 42 vineyards (22 organic and 20 conventional) distributed along a geographic gradient from south to north over two seasons (spring and summer). The soil was analyzed to determine its chemical properties, including carbon (C), nitrogen (N), phosphorus (P), and pH. Agrochemicals were extracted using the QuEChERS method and quantified using LC-MS. Furthermore, the soil was examined for its enzymatic activity and biodiversity, encompassing bacterial, fungal, and faunal diversity.
Preliminary results showed that conventional vineyards had significantly higher total organic C (TOC), inorganic C (IC), total C (TC), and total N (TN) compared to organic vineyards ($P < 0.03$), while the pH was significantly lower in conventional vineyards (-7.15%). However, there was variability among sampling areas and seasons. In the northern area, pH, TOC, TC, IC, and TN were significantly higher in organic vineyards ($p < 0.001$), while they were lower in the other areas. The phosphorus content did not significantly differ between management practices and geographic areas.
Finally, agrochemical residues were found to accumulate significantly more in conventional vineyards compared to organic farming, while seasonal variation and geographic location had minimal effects. Together with enzymatic and microbial results, the networks will provide a potential monitoring approach for sustainable agriculture.

AGROECOLOGICAL MANAGEMENT IMPROVES SOIL FUNCTIONALITY AND ENHANCES ECOLOGICAL RESILIENCE UNDER MEDITERRANEAN CONDITIONS: A CASE STUDY IN APPLE-BASED INTERCROPPING SYSTEMS OF SEFROU PROVINCE, MOROCCO

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Soil ecosystems in Mediterranean regions are increasingly challenged by agricultural intensification and climate variability, which alter their biological balance and reduce long-term fertility. In the apple orchards of Sefrou Province (Morocco), conventional monocropping systems tend to accelerate soil degradation and nutrient depletion. Agroecological practices, by contrast, promote soil regeneration through plant diversity and organic processes.

This study compared two management systems: a conventional apple monocrop and an agroecological system combining apple trees with intercrops of rosemary (*Rosmarinus officinalis*), faba bean (*Vicia faba*), and rapeseed (*Brassica napus*). Key soil parameters were analyzed, including organic matter, major nutrients (N, P_2O_5, K_2O), pH, electrical conductivity, and calcium carbonate content. The agroecological system showed higher organic matter and nutrient contents, more stable pH, and lower salinity levels, indicating improved nutrient cycling, greater biological activity, and enhanced ecological stability.

Overall, the findings demonstrate that diversified agroecological management enhances soil functionality and resilience compared to conventional monocropping. Intercropping systems that integrate legumes and aromatic species under apple trees represent an effective strategy for maintaining soil fertility, improving ecological processes, and ensuring the sustainability of Mediterranean fruit-growing agroecosystems.

ROLE OF Ni-Fe COPRECIPITATION IN NICKEL UPTAKE BY PADDY RICE

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Keywords: Rice; Nickel; Fe-Ni coprecipitates.

The increasing concern for consumer health is pressing rice producers to reduce Ni concentration in rice, also in view of the upcoming limit of 1.5 mg kg^{-1} in white rice (July 2026). Water management in paddy fields affects Ni availability: flooding conditions promote the release of the Ni pool bound to Fe oxy-hydroxides, whereas drainage can induce Ni immobilization via adsorption/coprecipitation with newly formed Fe oxy-hydroxides. In rhizosphere, CO_2 dynamics and root exudates influence Fe-Ni interactions by altering precipitation/dissolution equilibria.

To simulate these interactions, we synthesized Fe-Ni coprecipitates at different Ni/Fe molar ratios (0.002, 0.02, 0.2), in the presence and absence of bicarbonate to replicate p_{CO2} as a simplified model for reactions occurring in paddy soils and in rice rhizosphere. Precipitation kinetics were monitored, and the solid phases were characterized for their surface properties, crystallinity, and Fe and Ni contents. To evaluate the uptake of Ni and Fe from the solids, an hydroponic experiment was performed with rice plants grown in presence of the coprecipitates.

The results showed that bicarbonate accelerated Fe and Ni precipitation and promoted Ni incorporation in the solid phase, enhanced the formation of lepidocrocite within the dominant ferrihydrite phase. Increasing Ni concentrations induced structural disorder and surface Ni enrichment. Hydroponic experiments revealed that Ni incorporated in the coprecipitates was promptly available for plant uptake and absorbed more than Fe: more specifically, rice roots showed Ni/Fe ratios > 1, indicating high bioavailability of the surface-associated Ni.

These findings indicate that Ni incorporated within Fe oxy-hydroxides when paddy soils are dried may be remobilized during redox and rhizosphere-driven cycles, becoming accessible for plants. The increasing adoption of alternate wetting and drying irrigation to save water and mitigate climate change may enhance these redox fluctuations, potentially promoting Ni release and accumulation by rice plants. The limited plant discrimination ability between Ni and Fe underscores the need for careful redox-based water management as a key strategy to mitigate Ni uptake, also ensuring sustainable rice cultivation under changing climatic conditions.

AGRONOMIC EVALUATION OF PHOSPHATE ORGANOMINERAL FERTILIZER PRODUCED FROM AQUATIC MACROPHYTE COMPOST

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Keywords: P accumulation, phosphorus fertilization and corn crops.

Aquatic macrophyte biomass has been widely investigated as a strategy for the restoration of degraded soils, promoting increases in phosphorus availability, organic matter content, exchangeable calcium, magnesium and potassium, soil pH, base sum, base saturation, and cation exchange capacity. However, information regarding its agronomic efficiency as a nutrient source for crops of economic importance remains limited. Thus, this study aimed to develop and characterize organomineral fertilizer (OMF) formulations derived from aquatic macrophytes and to evaluate their agronomic performance as a phosphorus source for corn (Zea mays L.).
Organomineral fertilizers were produced using composted aquatic macrophyte biomass and biochar obtained from this material as organic matrices, combined with monoammonium phosphate (MAP) as the mineral phosphorus source. The OMFs and MAP were chemically characterized, and all fertilizers presented total macronutrient contents above 5%, meeting the requirements established by Brazilian Normative Instruction No. 61 (July 8, 2020).
A greenhouse experiment was conducted to assess agronomic performance. Three OMF formulations were evaluated: (i) pelleted compost + MAP (CMAPpel), (ii) pelleted biochar + MAP (BMAPpel), and (iii) crumbled compost + MAP (CMAPcru), in comparison with MAP alone. Phosphorus was applied at rates of 45, 90, 135, and 180 mg P_2O_5 kg^{-1} soil. Corn plants were grown in pots containing 5.25 kg of soil under controlled conditions, with uniform fertilization of nitrogen, potassium, and micronutrients across treatments. After 51 days of growth, shoot dry mass, phosphorus accumulation, agronomic efficiency, and apparent phosphorus recovery were determined.
Across all phosphorus rates, the CMAPcru treatment resulted in the highest biomass production and phosphorus accumulation, closely associated with its superior apparent phosphorus recovery compared to the other fertilizers. Overall, the use of composted aquatic macrophyte biomass as an organic matrix in organomineral fertilizers proved to be a viable alternative to conventional MAP for phosphate fertilization. The CMAPcru formulation consistently outperformed the mineral fertilizer in all evaluated parameters, indicating strong potential for use during corn establishment. In contrast, the BMAPpel formulation showed the lowest agronomic performance, which was attributed to insufficient pellet disintegration and nutrient solubilization in the soil.

ENHANCING SOIL QUALITY AND CROP PERFORMANCE WITH BIODIVERSITY-BASED INNOVATIONS

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Keywords: Regenerative agriculture, microbial inoculant, biodiversity, microbial community functionality

Agricultural intensification and the effects of climate change are progressively compromising soil health, leading to negative impacts on fertility, environmental quality and the sustainability of production systems. The EU project SOILRES addresses these challenges by implementing biodiversity-based strategies and innovative soil improvers to enhance soil-plant-microbiome interactions across diverse pedo-climatic conditions.

The Italian Use Case (UC5) investigates organic-based systems under Mediterranean conditions, where soil degradation, low productivity and weed management under minimum tillage remain critical issues. The site tests a set of integrated innovations, including on-farm compost production from local biomasses, waste-biomass valorisation into highly humified composts and biostimulants, biochar-microbe formulations for seed coating, and machinery adapted to strip cropping and living-mulch systems.

Within this framework, the University of Naples Federico II (UNINA) contributes to the development and assessment of soil improvers and biostimulants applied in UC5. The research activity focuses on evaluating how composts, biochar, compochar (biochar and compost) and microbial-based products influence soil quality and crop performance. Particularly, our research unit integrates chemical, biological and physical analyses, including nutrient profiling, soil organic matter characterization, applying 13C CP-MAS-NMR spectroscopy, P availability, determination of inorganic and organic forms (31P-NMR), and evaluation of composition and functionality of microbial community. Germinability tests on biochar-coated seeds complement the evaluation of seed performance under direct-seeding conditions.

The combined analysis of soil properties, microbial functionality and crop parameters allows the identification of relationships between amendment composition, soil biological processes and system resilience. These results demonstrate the potential of biodiversity-based interventions under real farming conditions and contribute to the development of low-input, microbially driven and climate-resilient agroecosystems.

ISOLATION AND CHARACTERIZATION OF STRESS-ADAPTED PLANT GROWTH-PROMOTING RHIZOBACTERIA ASSOCIATED WITH TOMATO UNDER SALINITY AND DROUGHT CONDITIONS

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Keywords: Plant growth-promoting rhizobacteria (PGPR); salinity stress; drought stress; 16S rRNA sequencing; tomato rhizosphere

Tomato plants exposed to salinity and drought harbor rhizobacteria naturally adapted to these conditions, offering promising candidates for plant growth promotion. This study aimes at isolating and characterizing stress-tolerant bacterial strains from the rhizosphere and roots of tomato plants grown under either increasing NaCl (50-150 mM) and drought (30% field capacity) stress. Selective plating on NaCl- and PEG-amended media yielded 127 isolates, with salinity producing the highest recovery. Functional screening showed that isolates from drought and salinity treatments exhibited enhanced plant growth-promoting traits—including phosphate and potassium solubilization, nitrogen fixation, siderophore production, indole-3-acetic acid synthesis, and sulfur oxidation—compared to controls, with drought-derived root isolates displaying the broadest functional profile. Genetic characterization through 16S rRNA amplification, ARDRA profiling, and sequencing resolved the isolates into 83 distinct clusters representing 23 genera, dominated by *Pseudomonas* and *Bacillus*. Only 3.6% of isolates were potentially pathogenic, whereas 72% were confirmed or putative PGPR. Rhizosphere soil DNA was also prepared for metabarcoding analysis. Overall, salinity and drought were found to enrich for diverse, stress-resilient, and functionally robust PGPR, highlighting their potential for developing microbial inoculants to improve tomato resilience under abiotic stress.

EFFECTS OF REGENERATIVE ORGANIC AGRICULTURE ON SOIL QUALITY AND PLANT BIOCHEMISTRY

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Keywords: nutrients, Anthrosols, sustainable practices, bioeconomy models

This study examines the impact of regenerative organic agronomic practices on soil quality and their subsequent effects on crop biochemistry. The central research questions are: (1) How do soil properties—specifically nutrient concentration and biological activity—change following the application of regenerative techniques? (2) Are these changes in soil quality reflected in a higher concentration of nutrients and secondary metabolites in cultivated plants?
The methodology involves field experimentation at the European Regenerative Organic Center (EROC) platform. The project will employ practices such as crop rotations, cover crops, organic fertilizers, and minimal soil disturbance to enhance soil fertility and reduce environmental impact by limiting chemical inputs. Soil and plant biomass samples will be systematically collected and analysed. Laboratory analyses will focus on key soil health indicators, including organic matter content, microbial activity, and water retention capacity, alongside an assessment of crop quality, focusing on nutrient contents and secondary metabolite profiles.
The expected results include a significant increase in soil organic matter and microbial biodiversity, providing evidence of a direct biogeochemical link between enhanced soil health and improved plant biochemistry. Furthermore, the project anticipates demonstrating higher crop yields and quality, leading to more resilient agricultural production.
The potential impact of this project is to contribute to the development of a more sustainable and regenerative agricultural system. By preserving soil fertility and enhancing local resources, it aims to promote a circular bioeconomy, aligning with broader European environmental sustainability objectives and increasing farmer participation in the transition towards sustainable agriculture.

COMPOST-MEDIATED RETENTION OF ORGANIC XENOBIOTICS IN AMENDED AGRICULTURAL SOILS

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Keywords: pesticide, industrial pollutant, adsorption/desorption, digestate-derived compost

Anaerobic digestion (AD) has emerged as a technology of increasing relevance due to its ability to combine several advantages, including the sustainable management of agro-livestock wastes, the production of renewable energy, and carbon storage in the solid by-product digestate (DG). However, unsustainable agricultural practices, such as the excessive or improper use of plant protection products and the application of incompletely decontaminated solid and liquid wastes, have caused soil contamination, with potential negative impacts on ecosystems and food safety. Within the framework of the PRIN 2022 PNRR Project P20223YAYP, funded by the European Union – Next Generation EU, Mission 4, Component 2, Investment 1.1, this study investigated the effects of adding 2, 4, and 8% digestate-derived compost (CP) on the adsorption/desorption of the fungicide penconazole (PEN), the herbicide S-metolachlor (S-MET), and the xenoestrogen bisphenol A (BPA) in two agricultural soils sampled in Valenzano (SOV) and Trani (SOT), southern Italy.
Recorded adsorption isotherm data of the three compounds on unamended soil and soil amended with CP were interpreted using Henry's linear equation and the empirical nonlinear Freundlich, Langmuir, and Temkin models. The Freundlich model was the best fit for experimental data of all treatments, indicating heterogeneous substrate surfaces and multilayer adsorption of the compounds.
Compared to unamended soils, the addition of the highest CP dose (8%) increased the Freundlich constants, KF, of PEN, S-MET, and BPA by 2,9, 2,7 and 2.2 times, respectively, in SOV and by 50.1, 8.9 and 12.4 times, respectively, in SOT. Comparing the two soils, it was observed that all SOV treatments exhibited adsorption constant values much higher than those obtained with the other soil, and this was reasonably due to the significantly higher organic carbon content in SOV (37.9%) compared to SOT (9.4%). Desorption of the two pesticides from all treatments was slow and incomplete, and was only slightly reduced or not affected by CP addition, while BPA release from all treatments was negligible. Significant relationships were observed between the adsorption coefficients of the three compounds and the corresponding organic carbon contents, highlighting once again the central role of organic matter, both natural and anthropogenic, in the retention of organic contaminants. Further investigation on a larger scale and in planted soil is currently underway.

ANAEROBIC CO-DIGESTION OF BREWERY' SPENT GRAIN WITH WALNUTS FROM WOOD-PRODUCTION TREES, TO ACHIEVE OPTIMAL C/N RATIO AND IMPROVE THE BIOGAS YIELD

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Keywords: Biogas, Walnuts, Anaerobic Digestion, Methane, Circular economy

The main residual of beer production, referred as Brewery's Spent Grain (BSG), is an excellent raw biomass for biogas production. However, the C/N (organic carbon/organic nitrogen) ratio is not centered within the optimal range defined for the anaerobic digestion process, suggesting that the process efficiency could be enhanced by addition of appropriately selected agricultural residuals. In this regard, walnuts (*Juglans regia L.)*, produced from wood-production trees and therefore non-food-competitive, were selected. Walnut production generates a variety of by-products. Considering the walnut fruit structure, it consists of a green husk and a nut, the latter composed of the shell, septum, and kernel. Depending on the purpose of cultivation, all parts except the kernel can be considered by-products. In timber-oriented cultivation, however, even the entire fruit often represents a by-product, as nut production is not the primary goal.
Due to the high organic carbon content of walnuts, this study aims to assess the synergistic effect of co-digesting BSG, rich in nitrogen, and walnuts, in order to achieve increased biogas production compared to the digestion of the single biomasses. Moreover, the presence of shredded woody walnut shell, will make the residual digestate highly predisposed for final composting, since the presence of solid and, at the same time, highly bio-degradable, woody particles, could ensure higher permeability to the whole residual, thus favouring the aerobic reactions required for the final composting. The present study deals with biogas production from sole BSG, sole walnuts and mixtures containing both. The results were discussed in terms of overall quantity of biogas produced, time duration of the whole process and daily production.

FROM AGRI-FOOD WASTE TO MULTIFUNCTIONAL SOIL IMPROVERS: BIOSTIMULATION AND NEMATODE SUPPRESSION IN TOMATO PLANTS

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Keywords: Spent coffee grounds, wasted bread, *Trichoderma spp*., *Lactiplantibacillus plantarum* H64, plant-parasitic nematode.

The sustainable management of agri-food by-products and the maintenance of soil fertility are central challenges for modern agricultural systems, in a context characterised by high levels of food waste and progressive depletion of soil organic matter. This study aims to develop innovative strategies for the reuse of agri-food waste as new generation soil improvers (NGSI) with biofertilising properties, as well as biostimulant and phytoparasitic soil nematode control properties. To this end, wasted bread (WB) and spent coffee grounds (SCG) were tested, raw and bioprocessed, in the greenhouse cultivation of tomato plants infested with *Meloidogyne incognita*, comparing them with an untreated control and a synthetic nematicide reference, in order to evaluate their relative efficacy in terms of crop growth and productivity, modification of the chemical-physical properties of the soil and nematicidal effect against phytoparasitic nematodes. After chemical, physical and spectroscopic characterisation of WB and SCG, specific bioprocessing protocols were developed on a laboratory scale, potentially applicable on an industrial scale. Both WB and SCG were pasteurised at 60 °C for 30 minutes and then inoculated according to the following protocols: WB was subjected to an initial fermentation with *Lactiplantibacillus plantarum* H64 (LAB) at 30 °C for 24 hours [107 cfu/g] and a second fermentation with *Trichoderma asperellum* at 25 °C for 7 days [105 conidia/g]; SCG was inoculated with the fungus only. LAB was used for its ability to rapidly acidify a simple substrate such as WB, produce antimicrobial compounds and promote the competitive exclusion of pathogens. *Trichoderma asperellum* is more suitable for recalcitrant substrates, such as SCG, and for conferring biostimulant and biocontrol properties to biomass. Overall, the most promising preliminary results were obtained from the use of WB as raw and bioprocessed in terms of plant growth and production. Phytotoxicity phenomenon was observed on the theses treated with the chemical nematicide and, even more intensely, with SCG. Further research is needed to understand the chemical and/or microbiological mechanisms underlying these results.

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SOIL PHOSPHORUS LEVELS MODULATE THE EFFECTS OF *BACILLUS THURINGIENSIS* INOCULATION ON MAIZE

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Keywords: Plant growth-promoting bacteria (PGPB); phosphorus use efficiency (PUE); sustainable phosphorus management; microbial inoculants; plant biostimulants

Plant growth-promoting bacteria (PGPB) have emerged as a sustainable strategy to improve nutrient-use efficiency in crops. Among them, bacteria able to mobilize soil phosphorus (P) are promising for more efficient P management, and may also affect plant growth through indirect mechanisms. Inoculant performance can also depend on the level of available soil P. Therefore, this study evaluated the effects of P rates and *Bacillus* inoculation on maize development. A 45-day pot experiment was conducted with inoculation treatments (*Bacillus thuringiensis* RZ2MS9, RZ2MS9 (Δ*ipd*C) - knockout of the *ipd*C gene in the tryptophan-dependent indole-3-acetic acid pathway, and a non-inoculated control) and P rates applied as monoammonium phosphate (0, 5, 25, 45 and 65 mg kg^{-1}). Canonical variate analysis (CVA) indicated that P rate was the main factor associated with variation in root and shoot growth, available soil P, shoot P, and acid phosphatase activity, whereas inoculation caused smaller differences. At 0 mg kg^{-1} rate, available soil P was higher under inoculation (18-19%) than in the non-inoculated control, whereas at 65 mg kg^{-1} the control was 14% higher. Acid phosphatase activity was higher at 0 and 5 mg kg^{-1} with ΔipdC compared to control (25 and 45%), and decreased at the highest P rate, with no differences among inoculants. Shoot P accumulation increased as P rates raised, 6% higher with ΔipdC than the control, and inoculation did not affect shoot dry mass. Root surface area and branching were greatest in ΔipdC > RZ2MS9 > control. Overall, under low-P conditions, microorganisms can contribute to plant P availability through multiple mechanisms (including phosphatase activity) and via indirect effects such as root system expansion that enhances nutrient acquisition. The superior performance of ΔipdC for P-acquisition-related traits suggests that mechanisms beyond the tryptophan-dependent IAA pathway may contribute to root architecture and rhizosphere P dynamics, and should be investigated in future studies.

DISCOVERING THE POTENTIAL OF ENDOPHYTIC FUNGI ON RELEASING PHOSPHORUS FROM AN INSOLUBLE P-FORM

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Keywords: phosphorus use efficiency, nutrients, microorganisms, phosphorus solubilizing fungi.

Phosphorus (P) is a key nutrient for plant growth, but it is often immobilized in insoluble forms, particularly in arid and semi-arid regions where the abundance of carbonates in soil increases pH and exacerbate P deficiency. Despite soil P surpluses (~70%), over 55% of global cropland suffers low to medium-low P use efficiency (PUE) (MacDonald et al., 2011). Excessive P fertilization contributes to runoff and, consequently, to eutrophication causing environmental issues (Sharpley et al., 2013).

In this context, endophytic fungi have emerged as bio-compatible strategies to mobilize insoluble soil P. Non-pathogenic endophytes such as *Trichoderma* spp., *Piriformospora indica*, and *Penicillium* spp. colonize plant roots and enhance P availability through the secretion of organic acids and P-solubilizing enzymes (Mehta et al., 2019). While *Trichoderma* spp. has been widely reported to solubilize insoluble inorganic P sources, particularly tricalcium phosphate [$Ca_3(PO_4)_2$; TCP] (Boat Bedine et al., 2022; Bononi et al., 2020; Saravanakumar et al., 2013), their ability to solubilize hydroxyapatite remains poorly explored.

In this study, six *Trichoderma* spp. strains, isolated from the rhizosphere, were evaluated for their P-solubilizing capacity in presence of hydroxyapatite [$Ca_5(PO_4)_3(OH)$; Hap] in liquid culture. *In vitro* screening was carried out using a modified National Botanical Research Institute's phosphate (NBRIP) growth medium, where TCP was replaced with Hap (NBRIP-Hap). Fungal isolates were cultured on potato dextrose agar (PDA) for 6 days at 22 °C, and subsequently inoculated in triplicate into NBRIP-Hap and Malt broth under shaking (40 rpm). Culture broths were filtered and analysed after 1, 3, and 6 days to determine soluble phosphate concentration (molybdate blue method; Murphy & Riley, 1962), pH, electrical conductivity, biomass dry weight, and mycelial P content after 6 days. Results obtained will be presented during an oral presentation or as a poster.

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AGROECOLOGICAL ASSESSMENT OF IRRIGATION TECHNIQUES AND SOIL CARBON DYNAMICS IN POTATO CULTIVATION

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Keywords: Solanum tuberosum; irrigation techniques; carbon cycle; productivity.

Between 2022 and 2023, potato cultivation in Emilia Romagna declined by 3.5%, due to wireworm pressure, reduced phytosanitary effectiveness and decreased soil fertility. These factors lowered profitability and increased reliance on imports. To respond to these issues, the **P.A.T.A.T.A.** project was launched with support from the 2021-2027 Rural Development Program of the Emilia Romagna Region. Its goal is to regenerate the supply chain through sustainable agronomic practices, improved soil and water management, enhanced plant health strategies and mitigation of carbon cycle impacts. This study investigates the effects of 2 irrigation methods, sprinkler and precision, on chemical and biological characteristics of soil. Agroecological field measurements were considered to determine which technique is best for soil health and quality. Data presented here were collected in the first year of the trial, structured around the 3 phases of the potato crop cycle. Soil sampling took place at the Acqua Campus in Budrio (BO) under the supervision of CER (Canale Emiliano Romagnolo), using plots of 8×40 m and 4×40 m irrigated with sprinkler and drip systems, each applied at 2 water volumes 5 times per week. In total, 24 soil samples were taken from depths of 5-35 cm. Chemical analyses included Total Organic Carbon (TOC), ammonium, carbonates, Cation Exchange Capacity (CEC), pH and available phosphorus, along with soil texture evaluation. Biological assessments measured microbial respiration and biomass carbon. Every 15 days, agroecological indicators like compaction, moisture, temperature, electrical conductivity and CO_2 emissions were recorded. Nitrogen availability proved strongly linked to organic matter and management practices. Irrigation enhanced N retention by reducing leaching, although sprinkler systems showed less uniform distribution. Early findings suggest that sprinkler irrigation increases soil fertility by boosting phosphorus and organic matter, key factors for maximizing yields. Precision irrigation, in contrast, improved chemical stability and tuber quality, supporting more effective plant health management, though it showed little influence on organic matter content. Definitive conclusions cannot yet be drawn but early trends indicate that rainfall supports productivity, whereas precision irrigation offer advantages for pest control. The second year of trials will be essential to confirm these patterns and determine the most suitable irrigation strategy.

FERTILIZERS PRODUCTION FROM WASTES THROUGH PHOSPHORUS CHEMICAL PRECIPITATION: EVALUATION THROUGH GROWTH TESTS ON *LACTUCA SATIVA* L. AND MICRO-TOM

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Keywords: Circular economy, Critical raw materials, Phosphate salts, Struvite, Phosphatase activity.

Phosphorus (P) is a critical element for food security, due to its essential role in plant growth. In conventional agriculture, this element is mainly supplied by mineral fertilizers obtained from phosphate rock (apatite) that will become scarce soon. In parallel, the mismanagement of livestock manure and agro-industrial wastes can cause water eutrophication. Recovering P from these residues to produce fertilizers represents a promising strategy that both preserves the environment and ensures a sustainable supply of fertilizers. This study evaluated six potential P fertilizers recovered from sewage sludge ashes (SSA) and liquid fraction of digestate (LDF). From SSA, four precipitates (P1 - P4) were produced through acid leaching with H_2SO_4 and HCl followed by selective P precipitation with $Ca(OH)_2$ and PC8, a by-product of magnesite extraction. These processes recovered more than 68% of the initial P, and X-ray diffraction (XRD) analysis revealed that the precipitates were mainly amorphous. From the LFD two precipitates were obtained (P5 and P6) through Mg-induced precipitation using seawater bittern, a by-product of salt production, as Mg source. P5 and P6 were obtained using a Mg:P molar ratio of 2:1 and 20:1 respectively, recovering more than 80% of P in both cases. XRD analysis showed that P precipitated as struvite in P5 and in amorphous in P6. P2, obtained using H_2SO_4 and PC8, P4, obtained using HCl and PC8, and P5 resulted as the most promising fertilizers after a short growth test on lettuce. Thus, their agronomic performances were tested on tomato plants (Micro-Tom) as long cycle plant test. The recovered fertilizers were compared with $Ca(H_2PO_4)_2$ and poultry manure (PM) because the latter contains P and organic matter in analogy to P6. Overall, a positive correlation was observed between soil P-available, soil phosphatase activity ($n = 5$; $R^2 = 0.77$; $p<0.05$) and plant growth ($n = 5$; $R^2 = 0.84$; $p<0.05$). Only P6, did not improve plant growth and P uptake compared to the unfertilized control. The best results were obtained with P2 and P4, which promoted Micro-Tom growth equal to mineral fertilizer and PM, highlighting the potential of these recovered P-fertilizers as sustainable alternatives to conventional fertilizers to support crop production.

SIDEROPHORE-PRODUCING PLANT GROWTH-PROMOTING RHIZOBACTERIA AND THEIR ROLE IN IRON UPTAKE AND HEALTH OF TOMATO PLANTS

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Keywords: Siderophores; PGPR; Iron uptake; Tomato; Rhizosphere

Iron deficiency is a major limiting factor for plant growth and productivity, particularly in calcareous and alkaline soils where iron availability is low. Plant growth-promoting rhizobacteria (PGPR) capable of producing siderophores can enhance iron mobilization in the rhizosphere and contribute to improved plant nutrition and health. This study investigates the role of siderophore-producing microbes in iron uptake and growth promotion of tomato (*Solanum lycopersicum* M.), using Azerbaijani tomato hybrids as a model system.

Preliminary laboratory screening focused on the isolation and characterization of rhizosphere-associated bacterial strains with siderophore-producing ability. Selected isolates were evaluated through qualitative and quantitative assays to assess their iron-chelating potential. Greenhouse and open-field experiments were subsequently conducted to examine the effects of PGPR inoculation on plant growth parameters, chlorophyll content, and disease incidence under controlled and natural conditions. Rhizosphere colonization and persistence of inoculated strains were confirmed using molecular fingerprinting approaches.

Initial results indicate that PGPR inoculation enhances plant vigor, improves iron nutrition, and reduces disease symptoms compared with non-inoculated controls. These findings highlight the potential of siderophore-mediated microbial interactions as a sustainable strategy to improve crop performance. The study contributes to a better understanding of microbe-plant interactions and supports the development of environmentally friendly bioinoculants for sustainable tomato production.

RESEARCH AND DEVELOPMENT OF AMARANTH (*AMARANTHUS* SPP.) CULTIVATION IN CASTILE & LEON THROUGHOUT THE ENTIRE VALUE CHAIN

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Keywords: Amaranth, EMS Mutagenesis, Drought Tolerance.

Amaranth (*Amaranthus* spp.) is a gluten-free pseudocereal with high nutritional and nutraceutical value, characterized by a favorable protein and amino acid profile, the presence of bioactive compounds, and remarkable tolerance to adverse environmental conditions. Under current climate change scenarios, its cultivation represents a promising alternative for sustainable agriculture, particularly in regions such as Castile and Leon.

This study aims to develop and characterize novel amaranth varieties with enhanced tolerance to drought and heat stress, while maintaining or improving nutritional quality and agronomic performance under the agroclimatic conditions of Castile and Leon. To this end, chemical mutagenesis experiments are being carried out using *Amaranthus cruentus* treated with ethyl methanesulfonate (EMS), generating a genetically diverse mutant population for subsequent selection.

Preliminary physiological and agronomic assessments are currently underway to identify stress-tolerant lines, focusing on traits related to water-use efficiency, thermal resilience, and plant vigor. In parallel, nutritional and biochemical analyses are being optimized to evaluate changes in protein content, mineral composition, and antioxidant-related metabolites in selected genotypes. Substantial phenotypic and physiological variability is expected among the mutagenized material, providing a robust basis for selection.

The results of this research will contribute to the development of climate-resilient amaranth cultivars and provide valuable insights into plant stress responses from an agricultural chemistry perspective, supporting crop diversification, sustainable farming systems, and food security in Castile and Leon.

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INTEGRATED ASSESSMENT OF THE QUALITY OF HORTICULTURAL AND VITICULTURAL SYSTEMS OF CAMPANIA REGION THROUGH THE ONE HEALTH APPROACH

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Keywords: Soil quality, Crop well-being, Food safety, Environmental sustainability, Human health

The quality of agricultural systems derives from the complex interaction between soil, plants, and the environment, with soil microbiomes being one of the main regulators of productivity, resilience, and food security. In a region such as Campania (Italy), characterized by highly productive and specialized areas but exposed to potential environmental contamination, there is a need for an integrated approach capable of linking biological processes, physico-chemical dynamics, and effects on human health. To this regard, we are implementing a study based on the One Health approach, linking human well-being to food quality and safety, soil and environmental health, sustainable use of resources, and interdisciplinary collaboration. A couple of horticultural and viticultural systems of Campania, managed with either regenerative/sustainable or conventional techniques, will be selected to assess soil properties and health status by physico-chemical characterization, analysis of organic matter quality, biomolecular investigations of microbial and edaphic communities, in collaboration with microbiology researchers. At the same time, the quality and safety of agri-food products, together with the physiological state of plants, will be analyzed through morphological and biometric surveys, physiological investigations, and in-depth chemical and metabolomic analyses with the contribution of food science researchers. In addition, the project aims to optimize production processes by promoting the recycling and valorization of agri-food waste, while the presence, mobility, and human bioaccessibility of environmental contaminants, including potentially toxic elements, persistent organic pollutants, and microplastics, will be examined by advanced analytical approaches, refined by integrated modelling aimed at risk quantification and mitigation. The integration of these topics and datasets will lead us to propose innovative indicators capable of correlating microbiome functionality, soil quality, crop status, and food chain vulnerability, providing operational tools for more sustainable and informed management of production systems. The originality of the project lies in its ability to connect chemical, biomolecular and environmental analyses within a single conceptual framework, translating the One Health principles into a vision applicable to the agricultural reality of Campania region and focused on protecting the environment, food, and human health.

IMPACT OF ALFALFA-BARLEY INTERCROPPING ON RHIZOSPHERE MICROBIAL ABUNDANCE AND NUTRIENT-CYCLING GENES UNDER DEFICIT IRRIGATION

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Keywords: Intercropping, nutrient cycling, soil microbiome, functional genes

This study explores how legume-based intercropping affects soil properties and microbial groups involved in the nitrogen and phosphorus cycles, serving as a key strategy for improving agricultural ecosystem functioning, climate resilience, and nutrient efficiency. The research analyses a two-year field experiment conducted in Spain featuring an intercropping system of alfalfa (Medicago sativa L.) and barley (Hordeum vulgare L.) grown under a deficit irrigation regime. We quantified the abundance of microbial taxonomic markers (bacterial and archaeal 16S rRNA genes, fungal ITS) and key nitrogen and phosphorus cycling genes (nifH, archaeal and bacterial amoA, nirK, nirS, norB, nosZ, phoD) in rhizosphere and bulk soils over two growing seasons.

In the first year, bacterial abundance in bulk soil was significantly lower in sole legume than in sole cereal plots, while intercropping resulted in significantly lower rhizosphere abundances of bacterial amoA and nirK compared to cereal sole cropping. However, by the second year, intercropping significantly increased the abundance of bacteria and fungi in both the rhizosphere soil and cereal roots. This microbial stimulation was accompanied by a significant increase in functional genes associated with nitrogen cycling—specifically bacterial amoA, nirK, nirS, and nosZ—as well as phosphorus mineralization (phoD) within the intercrop rhizosphere compared to sole cereal systems. Furthermore, while initially lower in the first year, archaeal abundance in legume roots became significantly higher under intercropping by the second season. Although intercropping led to lower bulk soil abundances of nifH and nirS in the second year, these findings collectively suggest that intercropping progressively fosters a more robust and functionally active microbial community in the rhizosphere, enhancing the system's capacity for nutrient self-regulation.

SOIL MANAGEMENT AND CROP ROTATION EFFECTS ON CO_2, N_2O AND CH_4 EMISSIONS IN MEDITERRANEAN DRYLAND AGRICULTURE

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Keywords: Conservation Agriculture, greenhouse gas (GHG), diversification, agroecosystem sustainability

Understanding how soil management practices regulate soil ecological functioning and greenhouse gas (GHG) emissions is critical for designing resilient and climate-smart Mediterranean cropping systems. This study evaluates the effects of soil management practices—including no-tillage and minimum tillage—combined with legume-based rotations on soil CO_2, N_2O, and CH_4 fluxes in a long-term field experiment located in Castilla y León (Spain). During the 2023/2024 and 2024/2025 growing seasons, soil GHG emissions were measured periodically from sowing to harvest across 36 experimental plots, 18 managed under minimum tillage and 18 under no-till. Both management systems followed the same crop rotations—wheat-oat-barley, and wheat-chickpea-barley—with three replicates of each rotation per management system. Soil GHG fluxes were measured using the static chamber method, a widely applied approach for quantifying soil GHG emissions. Gas samples were collected at regular two-week intervals throughout the growing season, with increased sampling frequency in the days immediately following fertilization events. All samples were analyzed by gas chromatography.
Preliminary results indicate that both fertilization events and intense rainfall episodes triggered pronounced increases in CO_2 and N_2O fluxes, with statistically significant differences observed between the two soil management systems at specific dates. Additionally, differences between crops were observed, highlighting the influence of crop type on soil GHG emissions. In contrast, CH_4 fluxes remained near neutral or slightly negative, indicating that the soil did not act as a major methane source or sink. These findings underscore the critical role of soil management in modulating short-term GHG flux dynamics in Mediterranean dryland agroecosystems. Moreover, they provide relevant insights for the design of sustainable management strategies aimed at mitigating climate change impacts and improving soil health.

ECOLOGICAL MEMORY AND RESILIENCE OF SOIL MICROBIAL COMMUNITIES UNDER PRESS-PULSE DROUGHT

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Climate change is one of the greatest threats to ecosystems, especially increasing the frequency and intensity of extreme events such as droughts and heatwaves, which impose severe stress on all organisms, including soil microbial communities. Soil microbes play essential roles in terrestrial ecosystem functioning including organic matter decomposition, nutrient cycling, and carbon storage. However, how the interactions between chronic (press) and extreme (pulse) droughts influence soil microbial community structure and functional recovery, and ecosystem stability remains poorly understood. Therefore, we hypothesize that soil microbial communities with prior exposure to press drought will exhibit enhanced resistance and faster recovery after a pulse drought, thereby mitigating drought impacts on ecosystem functions. To test this hypothesis, soils from three grasslands with varying precipitation histories will be used in controlled mesocosm experiments. Treatments will include a six-month press drought (reduced precipitation), a two-month pulse drought and an ambient control. Microbial composition will be analyzed using 16S rRNA and ITS sequencing, while microbial function will be assessed through soil respiration, enzyme activities, microbial biomass, and nutrient cycling measurements. Microbial biomass will be quantified using a modified mini-vial chloroform fumigation method, which shows strong relationship with the classic desiccator method while being more energy-efficient and practical for processing the large number of samples. This research will elucidate mechanisms of ecological memory and resilience in soil microbial communities, providing insights for predicting ecosystem responses under future climate extremes.

FUNGAL-BACTERIAL COMPOSTING SYSTEMS FOR SUSTAINABLE AGRI-FOOD WASTE VALORIZATION

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Keywords: Composting bioreactors, agri-food waste, circular agriculture, fungal biotransformation

The increasing generation of agri-food waste (AFW) requires sustainable strategies for its recovery and valorization. Four organic waste matrices were assessed in bioreactors: olive pomace (OP) and lemon/orange pomace (LOP) as substrates, and *Posidonia oceanica* detritus (POD) and pruning residues (PR) as bulking agents. Lignocellulolytic fungi and bacteria enhance compost quality by accelerating degradation and promoting the formation of high-value compounds. Their activity contributes to soil fertility, supports beneficial microbial communities, and reduces dependence on chemical inputs, in line with the principles of circular agriculture and sustainable waste management. The matrices were chemically characterized (carbon, hydrogen, nitrogen, and sulfur content; carbon-to-nitrogen ratio; pH; electrical conductivity; volatile organic compounds) and inoculated with *Aspergillus niger*, *A. tubingensis*, *Trichoderma harzianum*, *Pleurotus ostreatus*, and *Laetiporus sulphureus*. Fungi significantly modified substrate properties, reducing pH and increasing electrical conductivity, both indicative of active mineralization processes. After 9 days, OP, LOP, and PR supported extensive mycelial growth (up to 9 cm), whereas POD was markedly reduced (≤ 0.5 cm). *A. niger*, *A. tubingensis*, and *T. harzianum* emerged as the most effective strains, showing strong colonization ability and degradative potential. Dual-energy computed tomography (DECT) revealed substrate-specific radiodensity changes: OP and LOP inoculated with *A. niger* and *A. tubingensis* showed increased median values (120 to 140-180 HU; 72 to 92-98 HU), indicating biomass accumulation and partial mineralization, while PR shifted to negative HU values (down to -541 HU with *T. harzianum*), reflecting structural disaggregation and pore formation. Overall, selected fungi improved substrate biodegradability, supporting composting efficiency. DECT proved a powerful non-destructive tool to monitor density and degradation dynamics during fungal biotransformation. This approach offers a promising strategy for AFW valorization, with further developments expected from the ongoing work on bacterial consortia.

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GENETIC DIVERSITY AND GENOME-WIDE ASSOCIATION STUDIES ON GAMMA-IRRADIATED BAMBARA GROUNDNUT CULTIVARS FOR IMPROVED YIELD AND DROUGHT TOLERANCE

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Keywords: Bambara groundnut, Yield improvement, Drought tolerance, Root microbial community structure, Genomic Selection
Climate change is causing a drastic reduction in crop yield thus worsening the problem of food insecurity, especially in the sub-Sahara African region with rapid population growth. Hence the need to diversify food options to nutritious and more climate-resilient neglected crops such as the Bambara groundnut. This study aims to generate new Bambara groundnut (*Vigna subterranean*) cultivars using seed-gamma-irradiation technology. A total of 40 well-characterized Bambara groundnut cultivars will be collected from germplasms available at the IITA, Nigeria, and the Faculty of Natural and Agricultural Science, North-West University, South Africa. Each variety will be divided into 6 groups and exposed to 6 gamma-irradiation dose *viz-a-viz* 0 gy (un-irradiated control), 10 Gy, 50 Gy, 100 Gy, 150 Gy and 200 Gy, respectively, to determine the optimum radiation dose. Afterwards, the irradiated seeds will be planted immediately using an Augmented Split Plot Design with two replications. Agro-morphological and yield data will be collected from F_1 according to the standard descriptors for Bambara groundnut. Furthermore, the F_2 genotypes with high-yield potentials and desirable agronomic traits will be evaluated for drought tolerance using agro-morphological, physiological, biochemical, and SNP markers, as well as plant-microbe interaction. Genetic diversity study and Genomic selection studies will be carried out by apply cutting-edge molecular biology techniques such as Genotype-By-Target Sequence (GBTS) and Genome-Wide Association Study (GWAS), alongside conventional agro-morphological characterization to identify higher-yielding and drought-tolerant cultivars, as well as map the QTLs controlling these important agronomic traits. The microbial community structure around the root nodules of elite cultivars will be evaluated using metagenomic analysis to determine plant-microbe interaction samples among elite/high-performing BGN cultivars to identify potential beneficial bacterial species nodulating the roots of the elite cultivars. This study is expected to generate high-yielding and climate-resilient Bambara groundnut cultivars, identify novel QTL linked to beneficial traits, and identify beneficial microbial species interacting with plant nodule to promote yield and climate resilience.

WINERY SLUDGE COMPOST AS A SUSTAINABLE AMENDMENT: IMPACTS ON SOIL FERTILITY AND RHIZOSPHERE BACTERIAL COMMUNITIES IN POT AND FIELD TRIALS

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Keywords: winery sludges compost, circular economy, soil fertility, soil enzymes, rhizosphere bacterial composition

The intensification of grape production driven by the economic importance of viticulture has increased the use of chemical fertilizers, contributing to declining soil fertility. In this context, organic amendments derived from waste materials offer a sustainable approach, in line with circular economy principles, to improving soil quality and fertility. This study evaluated the effects of compost derived from winery sludges (WSC) on soil fertility and rhizosphere bacterial composition in vineyards, under both semi-controlled (pot experiment) and field conditions. The pot trial was conducted on cv. Cabernet Sauvignon (*Vitis vinifera* L.) grafted on Kober 5BB (*V. berlandieri* x *V. riparia*) grown in 80 litres pots. The field trial was carried out using cv. Sangiovese (*V. vinifera* L.) vines grafted on 110 Richter (*V. berlandieri* x *V. rupestris*). Plants were organized in a randomized block design and treated with mineral fertilization, WSC and unfertilised control. Rhizosphere soil samples were collected at flowering, veraison and harvest. In the pot trial, alkaline phosphatase activity was generally higher than acid phosphatase activity. This enzyme showed significantly greater activity in mineral-treated samples at flowering, while WSC-treated samples exhibited higher activity at harvest. Urease activity followed a similar pattern. In contrast, β-glucosidase activity in WSC-treated samples declined over the season. In the field trial, WSC application significantly increased the activities of phosphatases, β-glucosidase and arylsulfatase from flowering to harvest. The rhizosphere bacterial community was characterized through 16S rRNA gene metabarcoding. In the pot trial, beta diversity was strongly influenced by sampling time, with samples clustering primarily according to collection date, whereas no significant separation was observed among fertilization treatments. Nevertheless, LEfSe analysis revealed that WSC treatment was associated to the highest number of discriminant genera. In the field experiment, both sampling time and fertilization significantly shaped the bacterial community structure. Consistently, WSC was characterized by the largest number of discriminant genera. Overall, these preliminary findings suggest that, regardless of the cultivation method or grape cultivar, the application of WSC can enhance soil fertility and rhizosphere bacterial composition, exerting a sustained and progressively increasing effect throughout the growing season.

INTEGRATING PLANT AND SOIL RESPONSES: EFFECTS OF A PLANT-DERIVED PROTEIN HYDROLYSATE AS A BIOSTIMULANT

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Keywords: biostimulants, protein hydrolysates, soil-plant-microbiome interactions.

Plant-derived protein hydrolysates (PHs) are emerging as promising biostimulants for improving plant nutrition and stress tolerance. Their activity is mainly attributed to peptides and amino acids acting as signalling molecules, although the mechanisms of action, dose-dependent effects and interactions within the soil-plant-microbiome system are still not fully understood. Moreover, compared to animal-derived products, plant-based PHs exhibit greater compositional complexity and may also contain non-protein compounds, such as phytohormones.

In this study, a maize gluten-derived protein hydrolysate (GDPH), obtained through enzymatic hydrolysis of wet-milling byproducts, was evaluated on the early table grapevine cultivar *Black Magic* (*Vitis vinifera*). The biostimulant was applied via fertigation at veraison. Soil applications significantly enhanced yield and fruit quality within 14 days, increasing anthocyanin and sugar contents, and berry diameter, while maintaining optimal firmness, leading to a selective transcriptional reprogramming of ripening-related pathways.

Building on this field evidence, the biological activity of GDPH was further investigated in different experimental systems to explore its effects on early plant development, plant-nutrient interactions, and soil biological properties. Priming experiments on tomato seeds (*Solanum lycopersicum var. Roma*) revealed a clear dose-dependent response: low concentrations promoted germination and seedling vigour, whereas higher doses caused inhibitory effects, highlighting the importance of optimizing the application rate. Experiments on tomato plants grown in hydroponic systems are currently ongoing to assess plant responses under controlled nutrient conditions. In parallel, to elucidate indirect mechanisms mediated by soil microorganisms, soil drench treatments are also underway on tomato plants, allowing for the evaluation of plant phenotypic responses and changes in soil microbial community composition through microbiome profiling. Finally, GDPH has been characterized by high-resolution Orbitrap mass spectrometry and will be further fractionated by FPLC to link specific molecular features with biological responses.

Overall, these results support the hypothesis that plant-derived PHs act through multiple, context-dependent mechanisms involving both direct plant signalling and indirect effects on the soil microbiome, providing a basis for optimizing the use of PH-based biostimulants in agriculture.

EVALUATION OF BIOSTIMULANTS EFFICACY AND THEIR INTERACTIONS FOR BIOFORTIFICATION AND INCREASED STRESS TOLERANCE IN HORTICULTURAL CROPS

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Keywords: biostimulants, abiotic stresses, agronomic biofortification, sustainability.

The Mediterranean region is increasingly exposed to abiotic stresses linked to climate change, with serious repercussions on agricultural productivity. Among the most vulnerable horticultural crops are tomato (*Solanum lycopersicum* L.) and lettuce (*Lactuca sativa* L.), which experience significant losses in yield and quality when exposed to adverse environmental conditions.

In this context, biostimulants represent an innovative and sustainable strategy to increase plant resilience. By activating natural processes, they can enhance stress tolerance, improve nutrient uptake, and increase overall crop efficiency.

At the same time, agronomic biofortification of microelements has gained strategic relevance in horticultural species, as these nutrients are often present in limited quantities resulting in widespread deficiencies in the human population. Beyond their nutritional role, inorganic elements also display biostimulant properties, supporting plant growth and strengthening resistance to environmental stressors.

The proposed research aims to select, evaluate and compare biostimulants of different origins for their ability to increase nutritional value and tolerance to abiotic stresses in tomato and lettuce, with particular attention to the synergistic effects between inorganic elements and other classes of biostimulants.

The experimental plan will include the selection of raw materials based on a critical review of the scientific literature, growth chamber trials to evaluate dose-response relationships, mode of application and mechanisms of action. Subsequently, greenhouse tests will be conducted to validate the results obtained.

Physiological, agronomic, molecular, and chemical analyses will be integrated to elucidate the mechanisms underlying biostimulant activity and to distinguish true biostimulant effects from those attributable to simple nutritional supply.

The ultimate goal is to generate robust scientific evidence on the potential of biostimulants as tools for improving crop resilience and nutritional quality, thereby reducing the overuse of agricultural inputs and contributing to a more sustainable food production system.

THE EUROPEAN EARTHONE PROJECT: AGROFORESTRY FOR SOIL HEALTH AND CLIMATE RESILIENCE

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Climate change and soil degradation represent two of the most pressing global environmental challenges. According to the FAO, approximately 25% of the world's soils are severely degraded, while an additional 50% are moderately damaged due to declining soil fertility. In particular, soil organic carbon has decreased as a result of deep tillage, intensive cropping, and insufficient carbon inputs. In this context, agroforestry systems play a crucial role in both climate change mitigation and sustainable land management. By integrating perennial woody plants with arable crops on the same land, agroforestry enhances resource efficiency compared to conventional monocultures, thanks to the structural and functional diversification of its components. Moreover, the inclusion of trees within agricultural systems provides a range of soil-related ecosystem services — such as improved fertility and better physical, chemical, and biological soil properties. Agroforestry also promotes biodiversity and contributes to carbon sequestration. The Earthone Project, funded by the European Union, aims to evaluate carbon sequestration, greenhouse gas (GHG) fluxes, soil health and quality, and crop productivity parameters to mitigate the adverse impacts of climate change. Ultimately, the project seeks to improve the carbon footprint of agricultural systems and support the transition toward climate neutrality. The project involves six pilot sites across Europe, including agroforestry systems in Spain, Italy, and Greece, wetlands in Croatia, and agricultural and grazing systems in North Macedonia. In Italy, the experimental plots are located at the *Sasse Rami* farm in Rovigo, managed by the Venetian Agency for Innovation in Agriculture. These plots build upon agroforestry trials initiated in 2009, based on wheat-soybean-maize-barley rotations combined with the cultivation of disease-resistant poplar clones. The University of Padua (UNIPD) research team focuses on assessing the effects of agroforestry systems on soil organic matter stabilization, soil microbial biomass, and enzymatic activities involved in carbon, nitrogen, and phosphorus mineralization. In addition, GHG fluxes are being monitored to evaluate the overall mitigation potential of agroforestry in relation to crop productivity. The database generated through the Earthone project will support the improvement of business models by creating added value for products and practices related to carbon sequestration, climate change mitigation, sustainable resource use, biodiversity conservation, and the enhancement of ecosystem services.

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AGROECOLOGY OF VINEYARDS: MANAGEMENT INTENSITY, MICROBIOME AND DISEASE FROM FIELD TO LANDSCAPE

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Keywords: microbiome, grapevine, crop management, pest control

Viticulture is a sector of great agricultural and cultural importance, but its sustainability is challenged by intensive management practices, biodiversity loss, and plant diseases. Grapevines host a diverse microbiota that plays a key role in plant health, nutrient cycling, and resilience to biotic and abiotic stresses. Agroecological practices that support soil and plant microbiome diversity can help reduce chemical use and improve natural pest control. At the same time, vineyard abandonment, an emerging trend in many regions, can alter ecosystem functions, creating both risks such as pathogen reservoirs and opportunities for biodiversity recovery and ecological restoration.

This PhD project aims to investigate how different vineyard management regimes influence biodiversity, soil and plant microbiome structure, grapevine physiology, pest and disease dynamics, and key ecosystem services. Microbiome composition will be analysed across multiple vineyard compartments (soil, canes, leaves, grape berries) to assess the effects of pest control strategies, irrigation, and weed management on associated microbial communities. In addition, the ecological consequences of pesticide use will be investigated by comparing untreated leaves with those treated using different fungicide products. The research integrates systematic literature review, field surveys, molecular microbiome analyses, and mechanistic and data-driven disease modeling.

This project aims to help develop more resilient vineyards by showing how agroecological practices and the microbiome support plant health and sustainable landscapes, reducing the need for chemical control.

USE OF INTERCROPPING TO INCREASE SUSTAINABILITY OF STRAWBERRY CULTIVATION IN MOUNTAIN AREAS

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Keywords: strawberry, vegetable crops, mountain farming; sustainability; agroecology; intercropping; soil sickness

The project "Use of intercropping to increase sustainability of strawberry cultivation in mountain areas" investigates how long-term monocropping of strawberries affects soil health. Continuous cultivation of the same crop in the same field often leads to soil degradation, commonly known as soil sickness. This reduces plant performance and yield while increasing the need for external inputs such as mineral fertilizers and plant protection products. To address these challenges, the project explores agroecological strategies, with a particular focus on intercropping systems. Current research activities compare the performance of strawberry plants grown in two contrasting soil conditions: healthy soils, previously planted with brassicas as part of crop rotation and tired soils, where strawberries have been continuously cultivated for the past five years. In addition, eleven different strawberry intercropping systems are being tested to evaluate their agronomic and economic potential. This approach not only supports soil health but also expands the diversity of products harvested from the same area of land. Preliminary results indicate that intercropping strawberries with selected vegetables can be a promising option for mountain farms. Different intercrops have shown particularly positive outcomes in terms of plant growth, fruit yield and quality with potential profitability for growers.

USE OF EMBIO TO REDUCE TOXIC AND ODOROUS COMPOUND FROM SEWAGE SLUDGE AND ANALYSIS OF VOLATILE COMPOUND USING MASS SPECTROMETRY GAS CROMATOGRAPHY.

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Keywords: sewage sludge, effective microorganisms, gas chromatography, circularity, odorous compound

In recent decades, great attention has been devoted to the recovery of nutrients from secondary resources and their reuse in sustainable agriculture.

Centro Agricoltura Ambiente "Giorgio Nicoli" (C.A.A.) has pioneered treatments at its Crevalcore (BO) facilities where sewage sludge is accumulated and processed, the sludge is kept in fifteen tons tanks and constantly mixed to avoid anaerobic fermentation since is transported to other facilities for its disposal. Although sludge is rich in water and organic matter, with the potential to be a rich soil amendment, it often harbours contaminants and malodorous volatiles, that pose environmental and health risks.

This project aims to reduce sludge derived odorous molecules (aliphatic and aromatic hydrocarbons, sulphur- and nitrogen-based volatiles) and degrade hazardous organic pollutants by applying a commercial product (EMbio) containing a consortium of the so called Effective Microorganisms (EM).

The experimental design was as follows: two tanks of untreated sludge (sample V8) as control, two tanks were inoculated with a single EmBio treatment (sample V7), and two tanks were inoculated with a double EmBio treatment (sample V7 DT). After one month from the inoculum the sludge was sampled collecting three grams of material, in vial for gas chromatography, from three different layer of the tank. The volatile organic profiles were analyzed by HS-SPME GC-MS on the three treatments and the results obtained showed that single EmBio dosing (V7) achieved drastic reductions in high impact aromatics and linear and branched alkanes (C10-C16) exhibited partial decreases only in V7 DT.

Microbial plate counts highlighted a surge in viable bacteria post EmBio treatment. Analysis were performed on aerobic and anaerobic TSA plate and on ather anaerobic medium such as Wilkins-Chalgren (WS). The results confirm that EmBio fosters microbial proliferation while modifying the volatile compound profile toward odour mitigation and reduction of organic and inorganic pollutants.

The EmBIO treatment reduces phenolic and indolic odorants and lowers hydrocarbon loads, improving the social acceptance of land-applied sludge and potentially mitigating greenhouse gas emissions from conventional disposal practices. A better-characterized and readily testable microbial co-culture would enhance process control and treatment reliability, offering opportunities to align wastewater management with circular and climate-smart agricultural strategies.

K AND Mg PARTITIONING IN COFFEE PLANTS UNDER HIGH K AND LOW Mg SUPPLY

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Keywords: K:Mg ratio; Nutrient imbalance; Tissue accumulation; Hydroponic system; Biomass production.

In coffee production, climate change is intensifying heat and drought stress, and potassium (K) fertilization is often adjusted to support stomatal regulation and plant water balance, particularly during high-demand stages such as the reproductive phase. However, increasing K inputs may aggravate magnesium (Mg) limitation through K-Mg antagonism, generating nutrient imbalances that are not always evident in plant tissues. The objective of this study was to quantify organ-level K and Mg partitioning and tissue K:Mg ratios under contrasting K-Mg supply. This effect was assessed in young coffee plants grown in a hydroponic system using three regimes: C = Control (Mg 0.5 mM; K 4 mM), T1 = Low Mg × Adeq. K (Mg 0.1 mM; K 4 mM), and T2 = Low Mg × High K (Mg 0.25 mM; K 12 mM). These regimes were selected from a previous screening experiment combining two K levels with four Mg levels. K and Mg were quantified in young leaves, old leaves, stem and roots, and nutrient accumulation (mg organ^{-1}) and the K:Mg ratio (mass ratio; K/Mg from concentrations in g kg^{-1}) were calculated. Data were analysed by one-way ANOVA and Tukey's test ($p \leq 0.05$), with assumptions checked using Shapiro-Wilk and Levene tests. K accumulation increased in young leaves (47.7, 83.7 and 60.2 mg) and stems (34.4, 49.7 and 37.1 mg) under C, T1 and T2, respectively, suggesting preferential allocation of K to more active tissues under Mg limitation. In contrast, Mg accumulation decreased in old leaves (6.75 mg in C vs 2.01 mg in T1 and 2.66 mg in T2) and in roots (6.94 mg in C vs 5.13 mg in T1 and 5.25 mg in T2), indicating reduced Mg acquisition and internal redistribution. As a consequence, the K:Mg ratio peaked in old leaves (7.7 in C, 34.5 in T1 and 26.4 in T2), highlighting this organ as a sensitive indicator of K-Mg imbalance. In addition, high K under low Mg (T2) was associated with reduced root, shoot and total dry mass compared with T1, reinforcing that fertilization strategies aimed at improving drought resilience via K should be accompanied by appropriate Mg management to avoid imbalances that compromise plant performance.

PREDICTING PLANT-ASSOCIATED MICROBIOMES THROUGH UAV MULTISPECTRAL REMOTE SENSING AND MACHINE LEARNING APPROACHES.

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Keywords: Plant-associated microbiomes, Multispectral UAV remote sensing, Floral and soil microbiome profiling, Machine learning-based prediction

Floral microbial communities play a key role in shaping plant-pollinator interactions by influencing nectar chemistry, volatile organic compounds, and flower attractiveness. These microbiomes are also involved in the transmission of beneficial and pathogenic microorganisms to pollinators, particularly bees, which are essential for global food security. However, current approaches to characterize flower- and soil-associated microbiota rely on invasive sampling and laboratory-based molecular analyses, limiting their scalability at landscape level.

This project aims to develop and validate a novel, non-invasive framework to profile and predict plant-associated microbial communities by integrating UAV-acquired multispectral imaging, plant and flower identity, pollinator biodiversity, and microbiome data. The approach will focus on flowering herbaceous species as well as perennial crops, allowing the investigation of both floral and soil-associated microbial communities within agricultural systems. Multispectral signatures linked to plant pigments, sugars, lipids, water status, and microbial metabolic activity will be correlated with microbiome composition derived from molecular analyses.

Multispectral data will be collected using drone-mounted sensors in open-field trials and controlled greenhouse experiments. Floral and soil microbiomes will be characterized through DNA extraction, qPCR, and next-generation sequencing of bacterial (16S rRNA) and fungal (ITS) markers. In parallel, pollinator biodiversity—particularly bees—will be assessed through standardized field surveys measuring abundance, species richness, and diversity indices. Machine learning algorithms, including Partial Least Squares Regression, Support Vector Machines, Random Forests, and Neural Networks, will be used to construct predictive models linking spectral data, plant identity, pollinator metrics, and microbial community structure.

Overall, this project proposes an innovative, scalable strategy for monitoring floral and soil microbiomes using remote sensing technologies, with applications in pollinator health surveillance, precision agriculture, and sustainable management.

ANTHROPIZATION OF AMAZONIAN SOILS: IMPACTS ON ORGANIC MATTER DYNAMICS

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Keywords: Land use change (LUC); SOM cycling; isotopic signature; deforestation.

Land-use change (LUC) promotes alterations in carbon (C) and nitrogen (N) dynamics and, therefore in the persistence of soil organic matter (SOM). Aiming to contribute to the understanding of SOM cycling in Amazonian soils, this study investigated the impact of LUC on C and N concentration and the isotopic signature in Acrisols down to one meter depth. The study area is located at Embrapa headquarters, Rio Branco, Acre State, southwestern Brazilian Amazon. Soil samples were collected from six layers to a depth of one meter under six land use types: regenerating forest after a 2011 fire (BA) and its native forest reference area (NFB); grass-based pasture with *Cynodon nlemfuensis* (PP) and mixed grass-legume pasture (*Cynodon sp. and Arachis pintoi*) (IP) since 2018; degraded pasture (DP) since 1974; and the native forest reference area for the pasture systems (NFP). Contents of C and N were determined by elemental analyses, and the $\delta^{13}C$ isotopic signature was measured by an isotope ratio mass spectrometer coupled to a CN analyzer. In the sampled environments, C contents ranged from 1.98 to 2.72% in the 0-5 cm layer and decreased with depth, reaching values between 0.26 and 0.43% in the 70-100 cm layer. No differences in C contents were observed between land uses, indicating that pasture introduction and management type did not affect C accumulation up to 45 years after deforestation. The C/N ratio ranged from 8.7 to 11.8 in the 0-5 cm layer and from 4.1 to 5.7 in the 70-100 cm layer, confirming an increasing degree of SOM humification with depth. In forest environments, SOM $\delta^{13}C$ values averaged -27.8‰ in the 0-5 cm layer and increased to -26.3‰ in the 70-100 cm layer, reflecting microbial discrimination processes that enrich SOM in ^{13}C. In pasture systems, SOM $\delta^{13}C$ values were less negative than in the respective native forest environments, indicating the incorporation of pasture-derived C (C_4) into SOM. The contribution of "new" C ranged from 52-37% in the 0-5 cm layer to 6-10% in the 70-100 cm layer. Although no changes in total C contents were detected, the introduction of pastures in Amazonian soils significantly altered SOM cycling by mobilizing/mineralizing the endogenous SOM (C3 derived). The replacement of C3-derived by C4-derived SOM in these Acrisols raises questions about the SOM persistence in Amazonian environment and the respective mechanism that govern it. Acknowledgements: Capes (BR), CNPQ (BR), INCT(BR), PRODIGY (GR).

CROP DIVERSITY MODULATES NUTRIENT AVAILABILITY, ENHANCING SOIL HEALTH AND YIELD IN BRAZIL

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Keywords: soil quality, cover crops, soil organic carbon, extractable potassium, phosphorus availability

Soil health regulates crop productivity, nutrient cycling, and resilience of yields In Brazil, national assessments remain limited and the evidence on how diversification, especially cover crops, scales to yield is still scarce. We compiled 593 sites with topsoil samples at 0-30 cm collected from 2021 to 2024 across major producing regions. A minimal indicator set (pH, available P, exchangeable K, bulk density, and soil organic carbon, with texture as a control) was scored using context-specific curves and integrated into a unitless Soil Health Index (SHI, 0-1). We also derived a nutrient availability and storage function (IN, 0-1). To track ecological pathways, we fitted a structural equation model linking crop diversity (richness, RIC) to SOC, IN, SHI, and crop yield. The selected model used maximum likelihood with robust errors and standardized variables ($n = 593$). Crop diversity increased SOC ($\beta = 0.12$, $p = 0.009$). SOC increased IN ($\beta = 0.47$, $p < 0.001$). SHI was jointly driven by IN ($\beta = 0.58$, $p < 0.001$) and SOC ($\beta = 0.41$, $p < 0.001$). Yield responded to SHI ($\beta = 0.24$, $p < 0.001$) and showed a small direct association with crop diversity ($\beta = 0.09$, $p = 0.021$). The direct IN to yield path was not detected ($\beta = 0.02$, $p = 0.785$). Explained variance was $R^2\_IN = 0.22$, $R^2\_SHI = 0.72$, $R^2\_yield = 0.07$, and $R^2\_SOC = 0.02$. Indirect effects were positive but modest: RIC to IN via SOC = 0.057 ($p = 0.010$), RIC to SHI via SOC and IN = 0.075 ($p = 0.058$), and RIC to yield via SHI = 0.018 ($p = 0.075$). Total RIC to yield effect was 0.109 ($p = 0.010$). Fit indices were CFI = 0.955, TLI = 0.851, SRMR = 0.038, and RMSEA = 0.158. Ecologically, more diverse rotations tend to build SOC and improve nutrient availability and storage, which elevate SHI and are linked to yield. This identifies nutrient status as a dominant channel through which plant diversity shapes soil functioning and crop performance under environmental variability. The small direct crop diversity to yield component is consistent with short term agronomic benefits such as weed suppression, better soil cover, and moderated microclimate. At national scale, programs that promote diverse cover crop mixtures and SOC-building practices can deliver combined benefits in soil condition, nutrient provisioning, and yield stability.

NO-TILL PRACTICE ENHANCES FABA BEAN PRODUCTIVITY AND NODULATION RESILIENCE UNDER CLIMATE STRESS

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Keywords: No-till, *Vicia faba* L., Nodulation, biomass production, Yield.

Conservation tillage practices, particularly no-till systems, are increasingly recognized for their potential to enhance soil health, crop productivity, and ecosystem resilience under the pressures of climate change and human-induced soil degradation. This study evaluated the effects of four tillage practices deep ploughing (DP), chisel ploughing (CP), minimum till (MT), and no-till (NT) on the agronomic performance of faba bean (*Vicia faba* L.) grown on a vertisol under Mediterranean conditions during two cropping campaigns (2019-2020 and 2020-2021). The experiment followed a randomized complete block design with three replications.

Results showed that tillage systems significantly affected all measured parameters, including grain yield (GY) and its components: above-ground biomass (AGB), number of pods per plant (NPP), 100-kernel weight (100-KW), number and dry weight of nodules, and biomass production at flowering. The no-till system recorded the highest grain yield (1,087 kg ha^{-1}) compared to conventional tillage (806 kg ha^{-1}). At the flowering stage, biomass production reached 11,750 kg ha^{-1} under deep ploughing and 8,583 kg ha^{-1} under no-till. Moreover, no-till enhanced nodulation performance, with a greater number (68) and dry weight (1.34 g) of nodules compared to other tillage systems.

Overall, the findings indicate that conservation tillage, particularly no-till, promotes favorable soil-microbe-plant interactions that improve soil structure, biological activity, and crop productivity. These interactions represent essential mechanisms for enhancing the adaptability and resilience of agroecosystems to anthropogenic stress and climate variability.

SOIL CARBON FRACTIONS AS EARLY MARKERS OF SOIL HEALTH CHANGES UNDER AGROECOLOGICAL MANAGEMENT PRACTICES.

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Keywords: POXC, stable carbon pool, labile carbon pool, SOC storage, innovative fertilizing practices

The HORIZON-MISS-2023-SOIL-01 project *"Innovative practices, tools and products to boost soil fertility and peat substitution in horticultural crops"* (SPIN-FERT) aims to improve soil fertility and health through integrated and agroecological practices, such as green manuring, compost application and the development of eco-friendly biostimulants. The project seeks to promote more resilient production systems capable of enhancing biodiversity and overall sustainability. The CREA-CI Caserta team contributes to Work Package 3, focused on demonstrating the feasibility of integrated soil management practices in Poland, France and Italy. These trials will assess both crop performance and changes in soil fertility and soil carbon (C) dynamics. Our specific task focuses on evaluating the effects of these practices on soil organic carbon (SOC) fractions, key indicators of soil health. SOC stocks will be measured at three time points (initial, mid-term and final) over a two-year period starting in November 2025. Given the relatively short duration of the project to assess a reliable evaluation of long-term SOC sequestration, we will also analyze soil C fractions POC (Particulate Organic Carbon), MAOC (Mineral-Associated Organic Carbon) and POXC (Permanganate Oxidizable Carbon), to better understand carbon dynamics under different soil management regimes. Recent studies highlight POXC as a predictable indicator associated with early SOC stabilization processes. Our research group has previous experience with POXC assessment from a long-term field study comparing conventional tillage and no-tillage systems. In that trial, no-tillage resulted in the highest POXC values, which correlated with higher MAOM (Mineral-Associated Organic Matter) content, confirming a trend in SOC stabilization. This background supports the use of POXC as an early indicator of whether agronomic practices promote long-term SOC stabilization. We have now started the analysis of first soil samples for SPIN-FERT project, representing the pre-treatment conditions of the three study sites. This initial phase forms the basis for developing sensitive and timely indicators of soil quality change.

BIOLOGICAL DRIVERS OF SOIL CARBON STABILIZATION UNDER SUSTAINABLE MANAGEMENT IN TROPICAL SYSTEMS

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Keywords: carbon stocks; Enzymatic activity; Mineral-associated organic matter; aboveground biomass; Savanna

Sustainable agricultural management practices are essential to enhance soil carbon (C) storage while maintaining productivity in tropical systems. This study elucidates the biological and biochemical drivers of soil organic carbon (SOC) stabilization using structural equation modeling (SEM) across long-term experiments conducted in Rio Verde (GO) and Rondonópolis (MT), Brazil. The SEM exhibited an excellent fit to the data ($\chi^2 = 7.68$, df = 9, p = 0.57; CFI = 1.000; TLI = 1.026; RMSEA = 0.000; SRMR = 0.067), explaining 39% of the variance in β-glucosidase, 24% in arylsulfatase, 43% in mineral-associated organic matter (MAOM), and 82% in total SOC. Aboveground biomass exerted a strong positive effect on β-glucosidase ($p < 0.001$) and arylsulfatase ($p < 0.001$), showing that increased residue inputs stimulated microbial activity. In turn, β-glucosidase significantly promoted MAOM formation ($p < 0.01$), which was the main determinant of SOC accrual ($p < 0.001$). The positive relationship between the aliphatic/carboxylate ratio and total SOC further indicated that soils with greater C stocks are enriched in hydrophobic aliphatic compounds, more resistant to microbial decomposition. This molecular pattern reflects advanced SOC transformation and stabilization within MAOM pools. Collectively, these findings demonstrate that higher aboveground biomass enhances enzyme-mediated processes that accelerate the conversion of fresh plant residues into stable MAOM, strengthening soil C persistence and functional resilience. This integrative understanding provides mechanistic evidence of how biologically driven pathways underpin the sustainability and climate-smart potential of tropical agroecosystems.

INNOVATIVE BACTERIAL BIOINOCULANTS BASED ON BIOPOLYMERS

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Keywords: Alginate, Bioinoculant, Lettuce, PGPR, Polyhydroxyalkanoates

The increasing pressure for green farming techniques demands the implementation of groundbreaking practices that target yields comparable by conventional fertilizers, thus strengthening the environmental integrity of farming operations and preventing the lasting deterioration of productive soil. Among these novel technologies can be found also biofertilizers that inoculate soil with plant growth-promoting rhizobacteria (PGPR), which is a diverse group of microorganisms recognized for their beneficial contributions (nitrogen fixation, phosphate solubilization, the synthesis of siderophores and phytohormones), alongside the production of protective exopolysaccharide alginate and intracellular polyhydroxyalkanoates that function as carbon storage under stress conditions.

The research presents an innovative method for biofertilizer production that uses *Azotobacter vinelandii* for in situ self-encapsulation within a gel carrier through the crosslinking of alginate, which is synthesized during the bacterial cultivation process. This creative approach simplifies our preparation methods, offering new possibilities for cost-saving measures and increasing the overall effectiveness of the process. To support this theory, selected bacterial strains underwent gelation trials in settings that support the development of alginate gel, employing 2% (w/w) $CaCl_2$ as a cross-linker. *Azotobacter vinelandii* CCM 289 was chosen based on its superior alginate production, efficient gelation performance, and demonstrated potential for synthesizing indole-3-acetic acid and siderophores.

A total of three cultivation experiments were carried out on the lettuce, incorporating various carrier compositions (cells in PBS; gel excluding cells; gel including cells; freeze-dried gel with cells; negative control). Primary variations between cultivation conditions were attributed to the disparity in soil quality and fluctuations in irrigation rates. The growth experiment was carried out under controlled irrigation and illumination. As the quality of the soil and the frequency of irrigation decreased throughout the experimental trials, the disparities among the various groups became increasingly apparent, demonstrated by a notable improvement in fundamental growth metrics (fresh/dry weight, lengths of plant components), in addition to favorable modifications in the composition of the soil microbiome.

EVALUATION OF INNOVATIVE PEAT-FREE GROWING SUBSTRATE COMBINED WITH BIOSTIMULANTS FOR VEGETABLE CULTIVATION IN POTS

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Keywords: Peat alternatives, Biostimulants, Vegetable crops, Pot cultivation, Plant resilience

The progressive reduction of peat in growing media is a major challenge for sustainable horticulture. Peat-free substrates from agri-food residues, combined with microbial and non-microbial biostimulants offer a prospective to enhance soil fertility, improve crop performance and resilience by reducing the reliance on non-renewable resources and synthetic inputs. Their efficacy, however, depends on a lot of factors making it essential to understand interactions among substrates, biostimulants, and the soil-plant system.
A preliminary pot experiment at the Ri.Nova experimental farm (Cesena, Italy) evaluated a peat-free substrate (Enomondo growing substrate, Enomondo g.s.) on lettuce under semi-protected conditions. Treatments included Enomondo g.s. alone, with 20-30% perlite, or with 20-30% frayed vine shoots, compared to a commercial peat-based substrate. Plant growth was monitored weekly using NDVI, and at 40 days leaf and root biomass and root morphology were assessed. Enomondo g.s., alone or with perlite, outperformed the control, with higher NDVI and biomass, while frayed vine shoots reduced growth, likely due to phenolic compounds. Three further pot experiments were conducted on lettuce, zucchini and tomato to test Enomondo g.s. with foliar, root or combined applications of biostimulants compared to commercial control and with two fertilization regimes (full fertilization and 50% reduced fertilization). Across all crops, Enomondo g.s. showed better performance, even with reduced fertilization compared to the peat-based control with full fertilization. The application of biostimulants had less evident effects, but in some cases improved plant performance. For instance, on zucchini, humic acids, *Paenibacillus polymyxa*, and *Bacillus megaterium* slightly increased the fruit number, provided early production and promoted root development. On tomato, *B. megaterium*, *B. stercois*, *P. polymyxa*, *Pseudomonas congelans*, and humic acids generally improved growth, with *P. congelans* and *B. megaterium* most promising. No pH-related issues were observed.
Overall, these results indicate that the peat-free Enomondo substrate is very promising for growing vegetables in pots. The targeted application of microbial and non-microbial biostimulants in innovative formulations could further improve crop performance in order to develop new strategies, feasible for farmers, that aim to optimize the use of synthetic inputs (such as fertilisers) in agriculture.

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RESPONSE OF DIFFERENT OILSEED CROPS TO SALINITY IN MARGINAL SOILS

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Keywords: Salt-affected soil, *Brassicaceae*, *Asteraceae*, Genotype screening, Field trials

Salinisation is one of the main threats to agricultural soils on a large scale. The accumulation of ions, such as Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-, affects millions of hectares of land and is caused by both natural factors related to climate, geology and soil morphology, and by human activities, i.e. irrigation. Climate change is likely to contribute to an increase in the extent of saline soils in the coming years. Plant species can be divided into those that are most sensitive to salinity and those that are able to grow in saline environments. The latter are particularly useful in phytoremenagment and represent a resource for the production of sustainable bioenergy, in line with the objectives of the European Green Deal. Among non-food oilseed species, those of interest for the enhancement of marginal soils show a tolerance to salinity that is still poorly understood and varies between species and genotypes. The species considered in the project include *Brassica napus* L., which is moderately tolerant, *Camelina sativa* L. and *Brassica carinata* which have not yet been studied extensively in this regard, , and *Carthamus tinctorius* L., which is known for its good tolerance to salt stress. We aim to characterise the salinity tolerance of these four species in order to select resilient genotypes for bioenergy production in salinised environments. In an initial phase, conducted under controlled conditions, at least 20 genotypes per species will be evaluated in response to different levels of salinity and different salts (NaCl, $CaCl_2$, Na_2SO_4). Germination, a particularly sensitive phase, will allow the most promising genotypes to be identified. The best 2-4 per species will then be analysed in pots throughout the entire crop cycle, monitoring growth, architecture, photosynthetic activity, stomatal conductance, fluorescence and seed production, including combined salinity × drought stress effects. Finally, multi-year field trials on naturally saline soils will allow the consistency of responses to be verified and transferable data to be consolidated. The expected results will help to fill the current gaps in knowledge on the salinity tolerance of the species considered, promoting the enhancement of marginal soils and the development of sustainable bioenergy supply chains.

MICROBIAL CO-INOCULATION TO IMPROVE SOYBEAN DROUGHT STRESS TOLERANCE

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Keywords: Drought stress, Soybean, Biostimulants, *Azospirillum*, *Priestia*

Soybean (*Glycine max*) represents a strategic crop for European agriculture, promoting crop rotation diversification, reduced nitrogen inputs per the EU Green Deal, and increased domestic plant protein production. However, its expansion in southern Europe is challenged by irregular precipitation during sensitive growth phases, worsened by climate change. Developing sustainable strategies to enhance drought tolerance is essential, and microbial biostimulants constitute a promising approach. Notably, *Azospirillum* and *Priestia* spp. can promote root proliferation to improve water uptake, produce phytohormones to regulate physiology, and increase antioxidant activity.
To this end, a co-inoculation and drought stress trial was conducted in Cadriano (Bologna) in 2025, using 24 large tubs under a plastic tunnel to exclude rain. Soybean (cv. EM Pura) was sown on May 13 at 30 plants/tub, with seeds coated in co-inoculants: rhizobia control or rhizobia combined with two *Azospirillum* spp. strains or one *Priestia* sp. strain. Soil moisture was monitored with FDR probes and managed via drip irrigation to maintain field capacity until drought imposition at full flowering, when water was withheld until 60% field capacity after one week, followed by rewatering. Throughout the cycle, phenology, nodulation (at flowering), biometric parameters, and physiological traits during stress (e.g., net photosynthesis, PSII efficiency, SPAD index) were measured; at manual harvest on September 22, yield components were assessed.
Statistical analyses (two-way ANOVA) showed no significant co-inoculant effects on nodulation, phenology, or biometrics prior to drought. Drought stress significantly reduced physiological parameters, such as net photosynthesis, yet seed yield remained unaffected across treatments. Notably, a significant treatment × water interaction ($p < 0.05$) emerged for stomatal conductance, with two strains mitigating reductions under well-watered conditions, alongside a marginal trend ($p = 0.07$) for pods/plant.
These results raise questions about drought intensity and biostimulant colonization in this soil context, as broader benefits were not evident. Moving forward, the experiment will be repeated with tweaked drought stress intensity and increased inoculant concentrations to ensure adequate microbial establishment. Participation in this winter school will provide expertise to optimize biostimulant strategies for drought-prone soybean agroecosystems in southern Europe.

ISOLATION, IDENTIFICATION, AND CHARACTERIZATION OF BENEFICIAL MICROBIAL STRAINS FOR AGRICULTURE AND INDUSTRIAL APPLICATIONS

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Keywords: PGPR; biofertilizer; drought; salinity; metagenomics

The Mediterranean region, including Italy, is under growing agricultural pressure as climate change increases the frequency and intensity of drought, drives soil salinization, and raises temperature extremes. Together, these non-biological stresses can reduce crop productivity, increase yield variability across seasons, and ultimately threaten farmer income and food security in vulnerable production areas.
At the same time, many conventional systems still rely heavily on synthetic fertilizers and other external inputs. While these approaches can maintain yields in the short term, they may worsen environmental impacts through soil acidification, loss of biodiversity, and greenhouse-gas emissions, conflicting with EU sustainability goals such as the European Green Deal.
In this context, plant growth-promoting rhizobacteria (PGPR) offer a practical nature-based option to support crops by improving nutrient availability, limiting pathogens, and enhancing tolerance to abiotic stress. Strains within genera such as *Bacillus*, especially those from already stressed environments, have been reported to cope with both salinity and drought through traits such as osmolyte synthesis and ACC deaminase activity that reduces ethylene-linked stress responses.
Despite this promise, a major hurdle is moving from laboratory discovery to reliable field performance. Many strains that look strong in lab tests fail to work well in real soils, where competition, predation, changing moisture or salinity, and management practices shape survival and function. Only a small minority of screened PGPR strains (around 5-10%) reach commercial success, often due to poor adaptation to dynamic soil microbiomes and variable environments.
Recent research also shows that plant stress resilience is not due only to a single "beneficial strain", but also depends on microbial interactions and the broader community setting. Microbial diversity and legacy effects in plant-soil systems have been linked to stronger resistance to drought, suggesting that maintaining or managing functional consortia may be as important as selecting individual isolates. In parallel, studies of microbial communities in highly variable natural environments show how metabolic specialization can emerge under strong selection by the environment.
This project will combine targeted genetic approaches in *Bacillus* to test the role of specific genes in plant growth promotion with plant-based assays under controlled conditions, and will further evaluate whether the observed effects hold in more complex soil and rhizosphere settings.

UNVEILING ADAPTATION TO RECURRENT DROUGHT EVENTS IN SOIL MICROBIAL COMMUNITIES

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Keywords: Soil microbial communities; Recurrent drought; Community assembly; Climate change; Ecosystem functioning

Microorganisms play a central role in regulating ecosystem functions, particularly carbon and nutrient cycling, yet most ecological studies implicitly assume that biological responses are driven solely by current environmental conditions. This assumption is increasingly inadequate as climate change intensifies the frequency and recurrence of extreme events such as drought. Growing evidence indicates that past environmental conditions can strongly influence present ecosystem responses, revealing a critical knowledge gap in understanding how recurrent stress events shape ecosystem resilience. Drought profoundly alters soil microbial communities by affecting water availability, nutrient dynamics, and soil structure, with cascading consequences for ecosystem functioning. Recent studies, including work by Prof. Canarini, suggest that soil microbial communities can develop a form of ecological memory under repeated drought, partially buffering ecosystem functions against stress. However, the mechanisms underlying this adaptation remain poorly understood. In particular, how recurrent drought influences microbial community assembly processes—through deterministic and stochastic mechanisms—and how these shifts contribute to functional stability is still unclear.
This presentation presents the conceptual framework and research objectives of an ongoing PhD project. The author is a first-year doctoral student, and the project is currently in its initial phase; therefore, no experimental data are available yet. The PhD research will experimentally evaluate the hypotheses outlined here by assessing how recurrent drought events shape soil microbial community assembly and the stability of key biogeochemical functions.
Addressing this gap is essential for improving predictions of ecosystem responses to future climate change and for informing sustainable soil and ecosystem management strategies.

FROM NUMERICAL MODEL TO SOIL: A PARAMETRIC STUDY OF CONTROLLED NUTRIENT RELEASE FOR SUSTAINABLE AGRICULTURE

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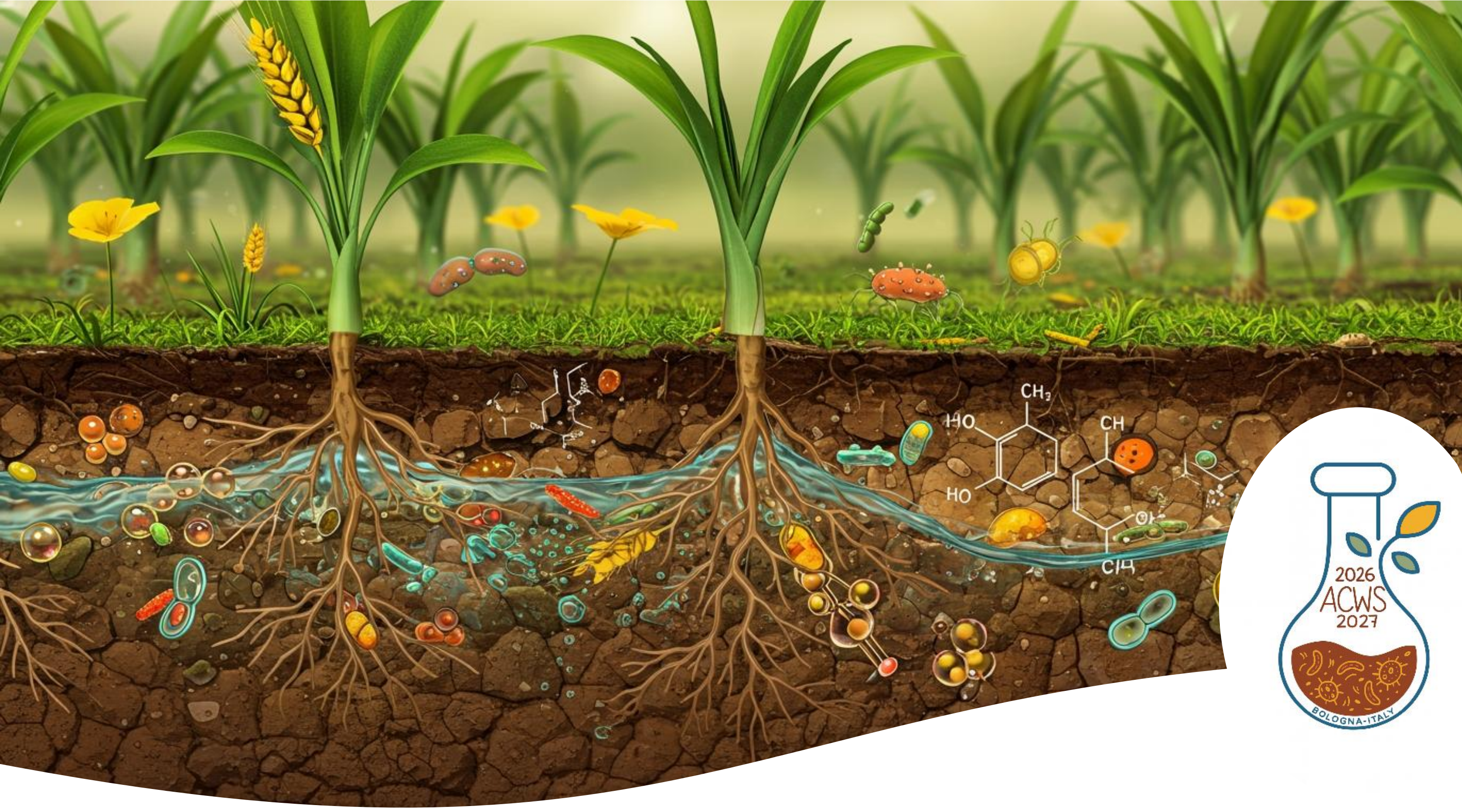
Keywords: Controlled-release of fertilizers; COMSOL Multiphysics modeling; Diffusion dynamics; Nutrient management; Sustainable agriculture

Systems based on controlled nutrient release represent an attractive approach for enhancing fertilization efficiency and minimizing environmental losses in agricultural production. Besides inorganic nutrients, organic soil amendments are also used in agricultural release systems. They can be utilized not only by plants but also by the soil microbiome. This study presents a parametric analysis of a numerical model describing the release of nutrients from a polymer-coated spherical particle, designed as a conceptual model for controlled-release fertilizers. Developed in COMSOL Multiphysics, the model simulates the diffusion process through a thin polymer layer into the surrounding environment and analyses the influence of key physicochemical parameters (e.g., layer thickness, diffusion coefficient, temperature, or initial probe concentration) on release kinetics.
Model parameters were selected based on values reported in the scientific literature, ensuring both physical consistency and practical relevance. This approach enables a quantitative understanding of system behaviour under a wide range of realistic conditions, helps identify the dominant factors affecting release dynamics, and verifies the model's numerical stability.
The findings complement experimental research and demonstrate how integrating computational modelling within the area of agricultural chemistry can contribute to the design of smart and sustainable fertilizers, supporting resilient soil-plant systems and more efficient nutrient management.



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